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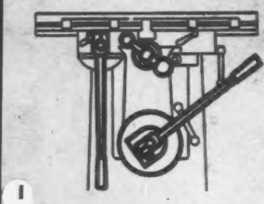

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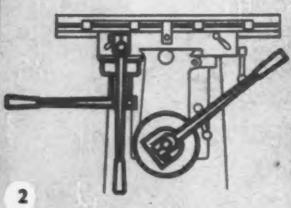

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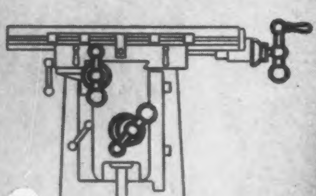

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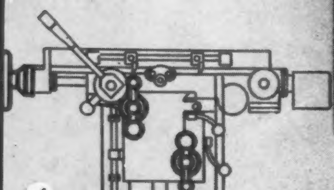

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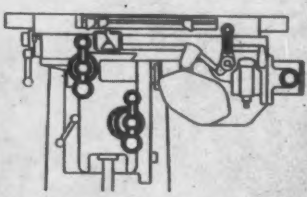
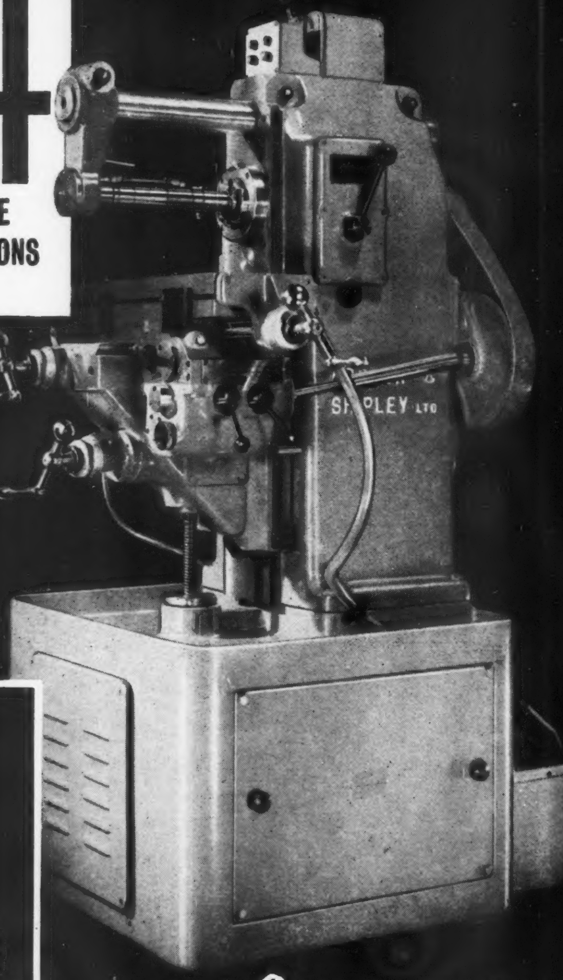


5 Automatic Cycle.



6 Normal automatic feed.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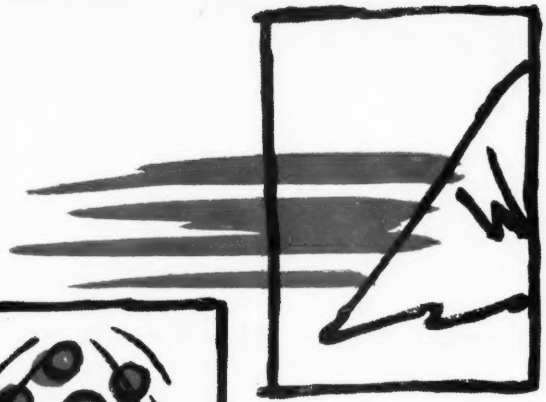

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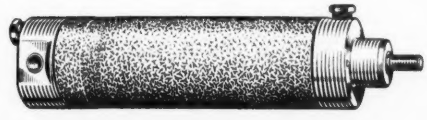

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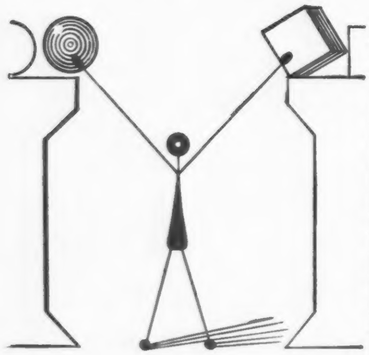
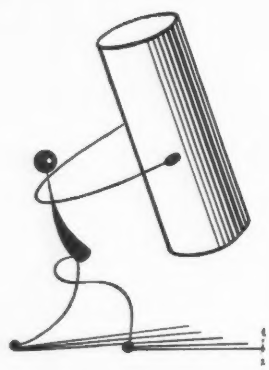
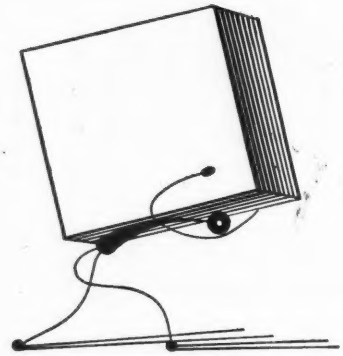


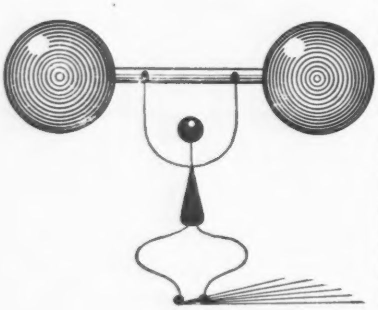
...reach...



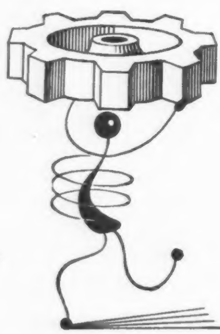
...grasp...



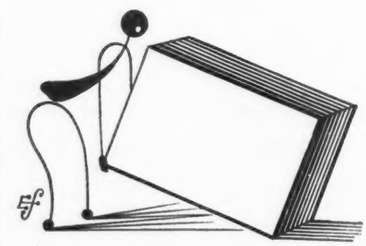
...carry...



...lift...



...turn...



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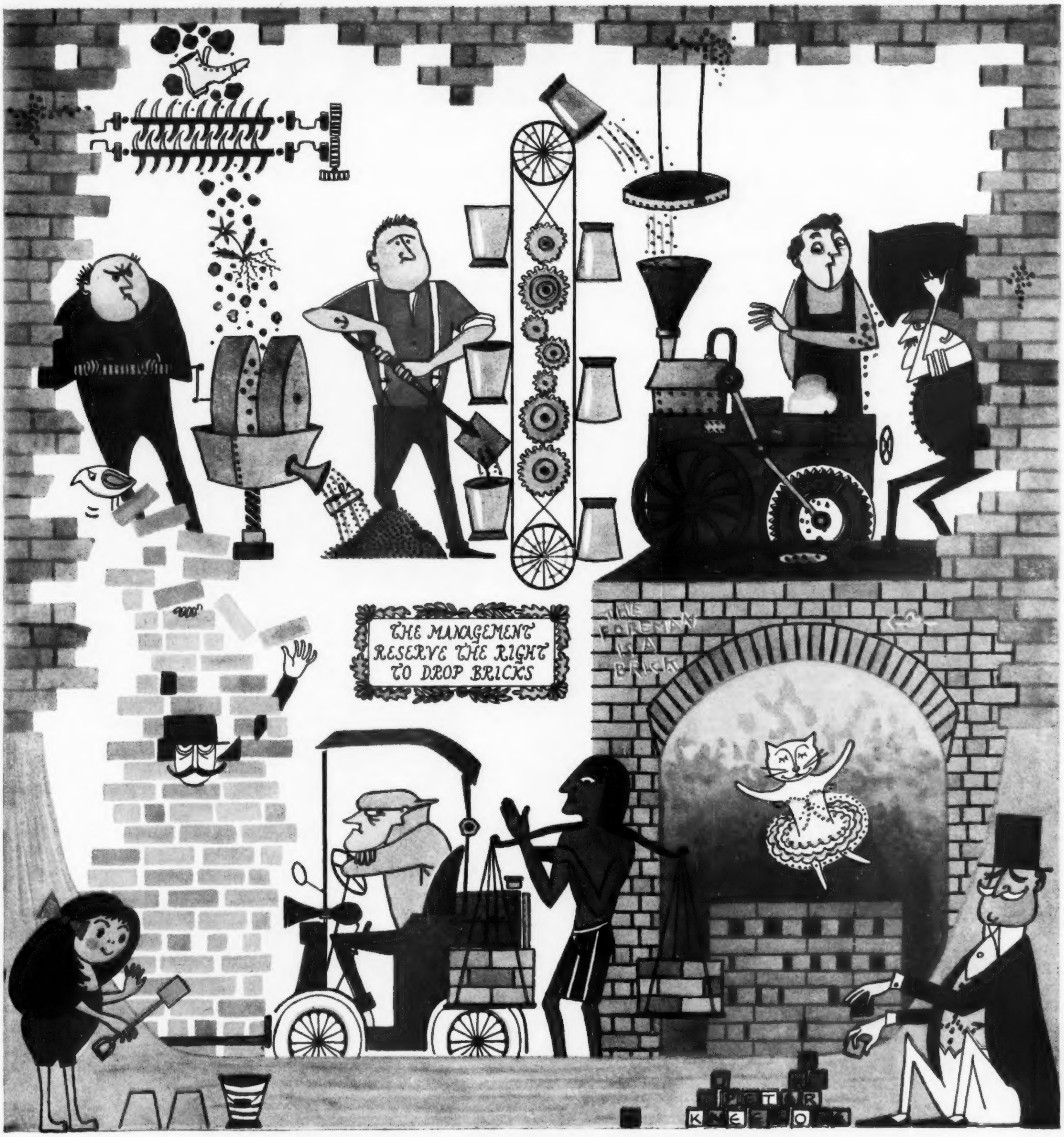

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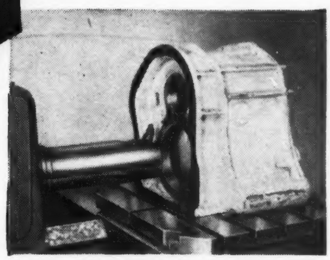

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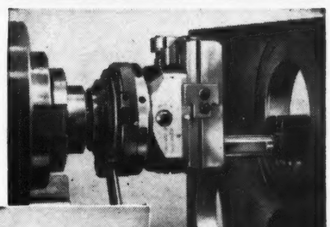

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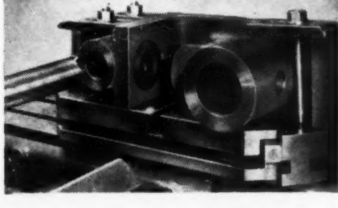

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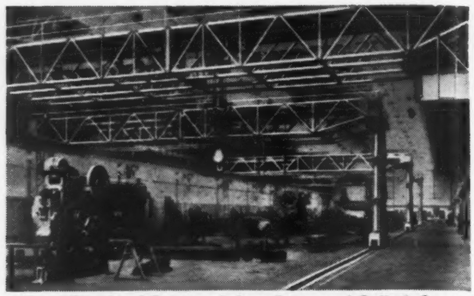
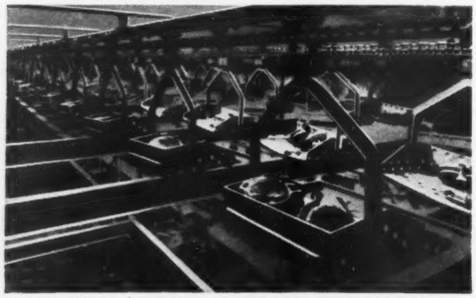
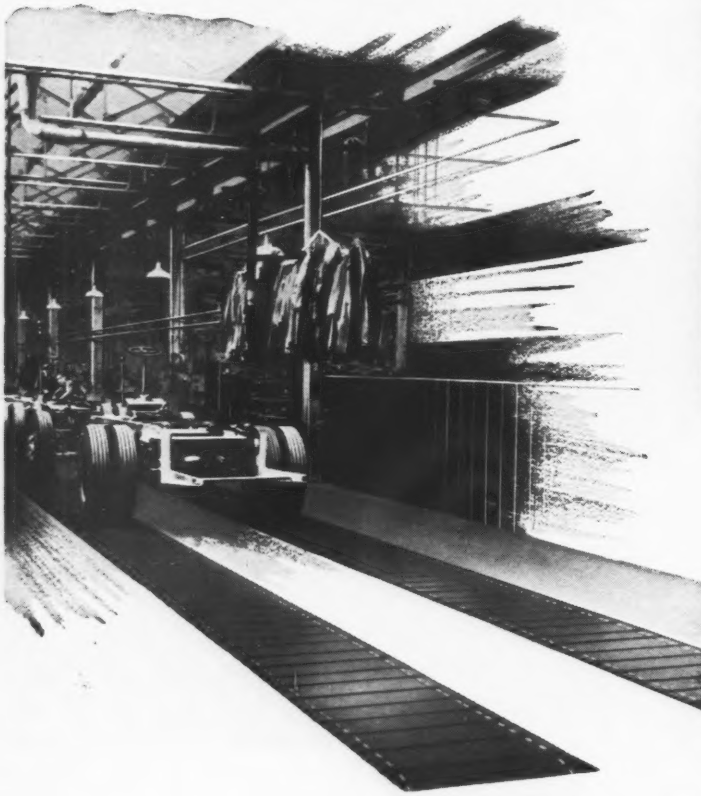


A 15 ton Overhead Crane and three 5 ton semi-Goliath Cranes in service with Euclid (Gt. Britain) Ltd., Newhouse, Lanarkshire



This Cooling Conveyor allows castings to cool while they are transported above floor level to the fettling shop



A Twin Slat Conveyor in operation at the A.E.C. works, Southall, Middlesex

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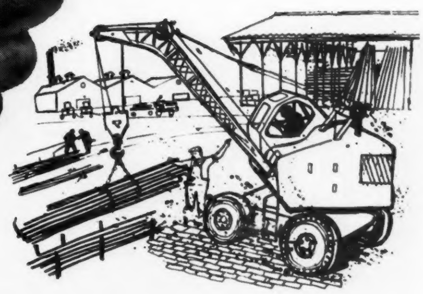

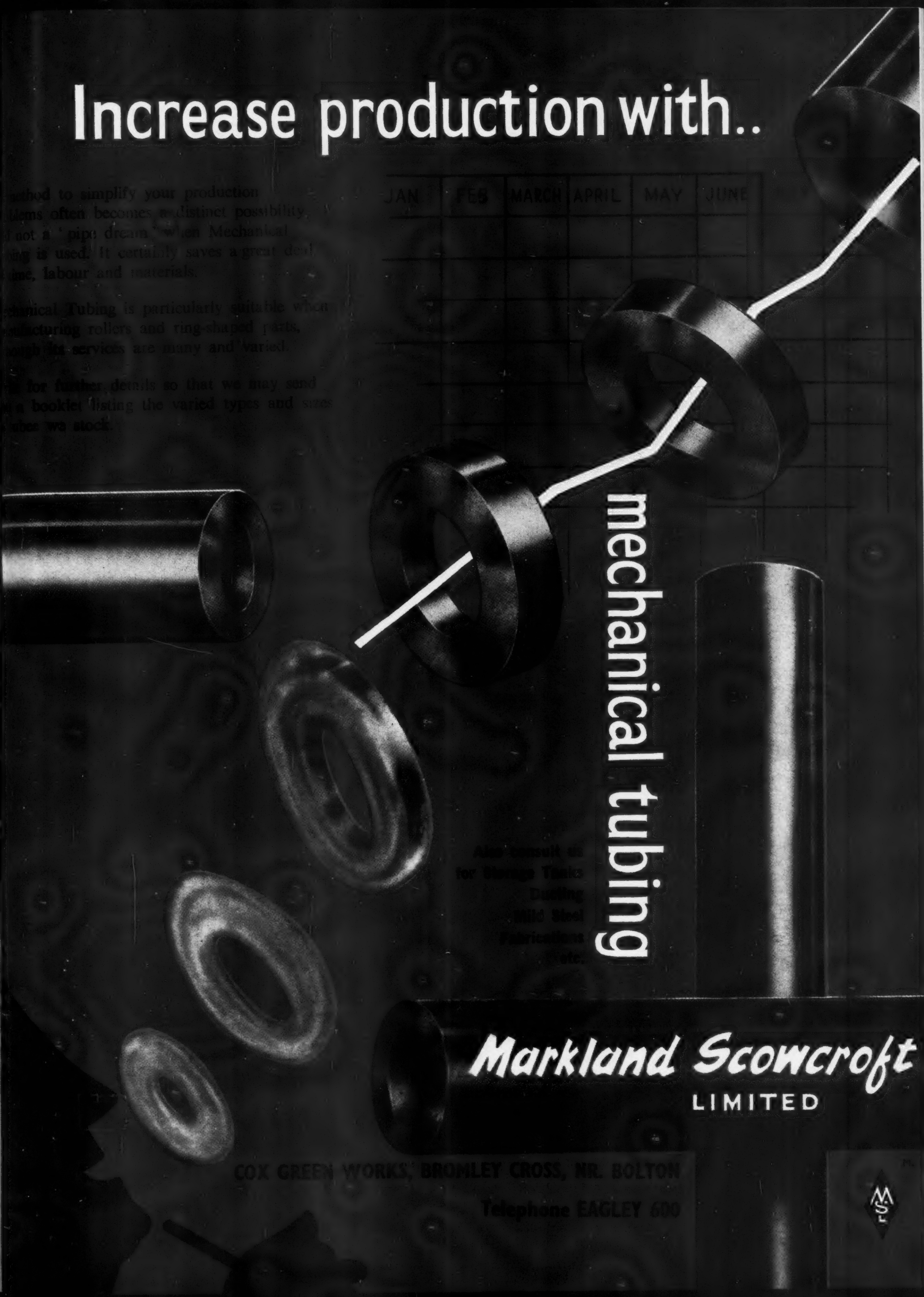
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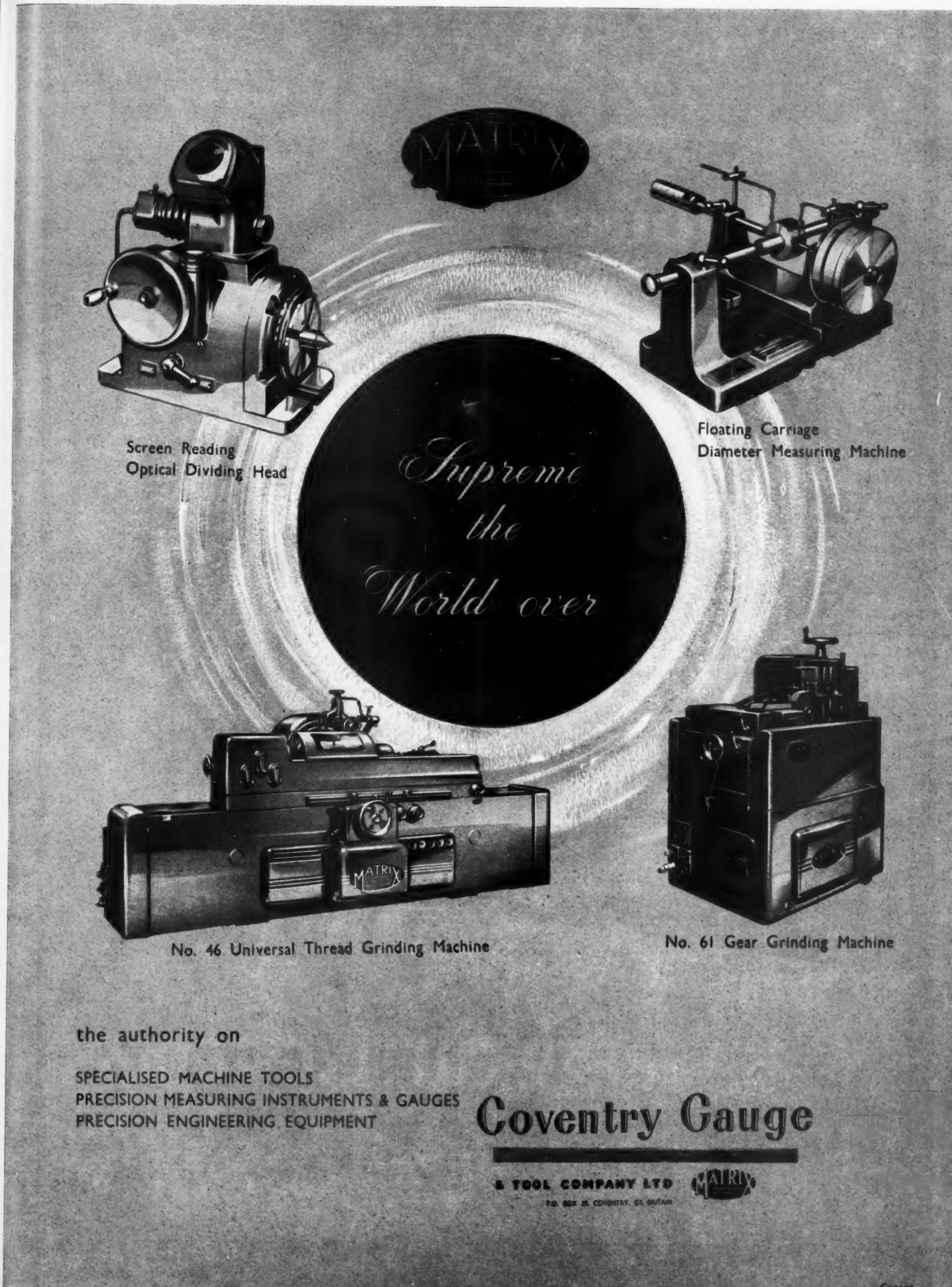
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Sixth Annual Conference on

"PROBLEMS OF AIRCRAFT PRODUCTION"

University of Southampton, 2nd/3rd January, 1958

THE Chairman, **Mr. D. L. Wiggins** (*Chairman of the Southampton Section*) speaking at the Opening Luncheon, said the Conference was fortunate in having so many distinguished guests, including the Mayor of Southampton, and Mr. James F. Grady, the American Consul in Southampton, at their sixth annual gathering to deliberate upon the problems of aircraft production. Mr. Boyd K. Bucey, who was to present the Lord Sempill Paper, had travelled several thousand miles to attend, and Mr. Wiggins was sure that in extending to Mr. Bucey a particularly warm welcome to the Conference, to Southampton and to England, he would be fulfilling the wishes of all present.

It was not their purpose to discuss the performance of fighters, the range of missiles, the pay load of air liners or even the height of Sputniks, but merely, assuming that any of those things were required, to see that as production engineers they produced them more economically and faster than hitherto. Very few aircraft in service, if any, had been conceived since the first Conference, and it was obvious that this time lag must be reduced. It was hoped that by holding these Conferences, the open discussions and free interchange of production techniques which took place would help to have aircraft flying longer in relation to production time, instead of being obsolete before they were built.

They must not be downhearted about the Government's action in the aircraft industry, any more than they should be downhearted about technical progress in Russia. Both these things were challenges to their productive skill. If they were optimists, they would believe that they lived in the best of all possible worlds, and only the pessimists would fear this to be true. If their American friends would excuse a little British pride, he would quote what Charles Churchill had written 200 years ago:

> "Be England what she will,
> With all her faults, she is my country still."

Mr. G. T. Dicks, J.P. (*Mayor of Southampton*), extended to the Conference a warm and sincere welcome to Southampton. There had always been, and he hoped there always would be, very happy relations between The Institution of Production Engineers and the local authorities. If they were to expect progress in their time, it was vital that all the links should be tied.

He would take his motto from the proverb: "Let a few words to the wise suffice". The last year had shown a vast amount of progress in all science and research. He felt that it was the wish of everyone, throughout the land, that 1958 should also be a tremendous year of progress, in science and research.

He hoped that the Conference would prove successful to them all, in every way, and that knowledge would be interchanged that could be developed and used in the interests of all concerned.

At the reception (left to right) Mr. James F. Grady, U.S. Consul in Southampton; Mr. Boyd K. Bucey; Mr. D. L. Wiggins, Chairman of the Southampton Section; and The Mayor of Southampton, G. T. Dicks, J.P.

The Chairman, introducing **Mr. James F. Grady** (*American Consul in Southampton*) said that in preparing the Conference programme the Section Committee had received the utmost co-operation from the Consulate in arranging for Mr. Bucey to attend the Conference. It was therefore appropriate, and they were honoured, that the Consul should be present to address them.

Mr. Grady would speak from a background of 30 years' industrial, educational and governmental experience.

Mr. Grady said he was greatly honoured to have a part in a Conference programme dealing with aircraft production, a topic of vital interest to everyone today. An industry that exported over one hundred million pounds' worth of equipment, as the aircraft industry in the United Kingdom did in 1956, and again in 1957, was obviously of tremendous importance to the economy of the country. It was no exaggeration to say that the eyes of the world were fixed today on scientific and technical developments in the aircraft industry, and hence the Sessions of this Sixth Annual Conference devoted to the improvement of existing methods and the development of new production techniques took on an added importance. Britain had again demonstrated her leadership in this field with the recent spectacular performance of the Bristol Britannia in its maiden flight on the North Atlantic run.

The theme of the Conference — "U.S. - U.K. Practice" — was of especial interest to him, as was any activity that affected closer relations between Britain and the United States.

Before making any observations on the theme of the Conference, Mr. Grady stressed that he was not competent to discuss the technical aspects of aircraft production, and said he was sure that the Chairman did not have in mind that he should launch into a field that would be covered expertly by the excellent speakers in the Conference. He had increased respect for the speakers who were to discuss these technical subjects, because he had spent several hours with them at dinner and a pre-Conference 'warm-up session' the previous night.

Mutual exchange of knowledge

His first observation was that the Conference, with representatives from Britain and the United States presenting Papers and participating in the discussions, was a practical example of the sharing of scientific and technical knowledge which could mean so much to both countries, and to the free world. On this subject, said Mr. Grady, he wanted to quote President Eisenhower's recent tribute to British inventiveness and leadership in research and development. In one of his talks with Mr. Macmillan in Washington, the President said: "Harold, you know I cruised briefly last summer on our newest aircraft carrier, the 'Saratoga'. And I found myself particularly interested in three things — the angled deck, the mirror landing system, and the steam catapult. The angled deck and the catapult have made our carriers much more effective, and the landing system has saved lives of our men. I found also that all three of them were British ideas, British inventions." And so in keeping with the theme of the Conference, Mr. Grady thought it would be

agreed that there was much to learn from one another, and that this exchange of ideas could be mutually helpful.

Next, continued Mr. Grady, he would like to pay tribute to the Boeing Airplane Company, not only for its great contribution to aircraft production in the United States, but also for making it possible for one of its top executives, Mr. Boyd Bucey, to participate in the Conference and to deliver the Lord Sempill Paper. Further evidence of the leadership of the Boeing Company and of its application of the principle of sharing knowledge was the fact that it enlisted the assistance of Professor Richards, of the University of Southampton, for a three-month period last year as a consultant. The letter which the Consulate received from the President of the Boeing Company regarding a visa for Professor Richards stated that " Professor Richards is a foremost authority on sound suppression, and it is in this capacity that the Boeing Airplane Company intends to utilise his services ". It had now been announced that Professor Richards' accomplishments had been given further recognition by the award of the O.B.E. in the New Year's Honours List.

The University's contribution

Paying a special tribute to the University of Southampton, which had made its facilities available to the Conference, as it had to so many other scientific, educational and cultural meetings during recent years, Mr. Grady said he had had the pleasure of participating in a number of such conferences and meetings. He was particularly interested in the activities of the University, because he had spent a good many years of his adult life in educational administration, and he had some appreciation of the contribution that a progressive and soundly administered University could make to the growth and development of a community and its industries and institutions.

In conclusion, Mr. Grady quoted from Mr. L. G. Burnard's Paper: " As much as any other, the British aircraft industry is vitally aware of the need for continued improvement of existing methods and the development of new production techniques. Almost every company has accordingly established a Production Development Department, not only to consider and develop new and improved processes, but to effect the widest possible dissemination of knowledge among production personnel. There is ample evidence that the principle of co-operation in this sphere has been and is being applied, not merely inter-departmentally, but throughout the companies of the industry as a whole."

He also quoted from Sir Matthew Slattery's recent article, " Aircraft Industry Looks Ahead ", in which, after referring to the export market of over one hundred million pounds, approximately 25% of the annual production, or in other words, a total annual production of over four hundred million pounds, he said : " Here is an industry that is a great national asset, that is worthy of support and encouragement."

To this forward-looking and hopeful note, said Mr. Grady, he added his congratulations to the participants in the Sixth Conference on Problems of Aircraft Production, which he was confident would make a notable contribution to the improvement of the aircraft industry.

Sixth Conference on

"PROBLEMS OF AIRCRAFT PRODUCTION"

Southampton, 2nd/3rd January, 1958

Theme : " U.S. — U.K. PRACTICE "

The Sixth Conference on " Problems of Aircraft Production ", promoted by the Southampton Section of the Institution, took place on 2nd - 3rd January, 1958, at the University of Southampton (by kind permission of the Vice-Chancellor). This issue of the Journal contains a report of the speeches made at the Opening Luncheon, and of the proceedings in Sessions I and II. Sessions III and IV will be reported in the April Journal.

OPENING LUNCHEON

Speakers : G. T. DICKS, J.P., Mayor of Southampton.
JAMES F. GRADY, United States Consul in Southampton.

Chairman : D. L. WIGGINS, M.I.Prod.E., Chairman, Southampton Section.

SESSION I
(The Lord Sempill Paper)

" MANUFACTURING IN THE AERONAUTIC AGE "

Speaker : BOYD K. BUCEY.

Chairman : The Rt. Hon. THE EARL OF HALSBURY, F.R.I.C., F.Inst.P., M.I.Prod.E., President of the Institution.

SESSION II

" MANUFACTURING PRACTICE — A REVIEW OF THE BRITISH AIRCRAFT INDUSTRY "

Speaker : L. G. BURNARD, A.F.R.Ae.S., M.I.Prod.E.

Chairman : E. F. GILBERTHORPE, A.M.I.Mech.E., M.I.Prod.E., A.M.B.I.M.

SESSION III

" SOME ASPECTS OF THE DESIGN, DEVELOPMENT AND MANUFACTURE OF THE P1 WING "

Speakers : F. BRADFORD, A.F.R.Ae.S., and G. H. TAYLOR.

Chairman : J. B. TURNER, M.I.Prod.E.

SESSION IV

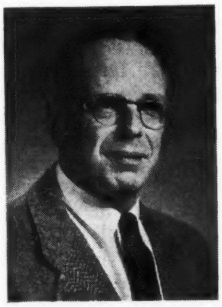
COMBINED DISCUSSION ON ALL PAPERS PRESENTED TO THE CONFERENCE

On the platform : BOYD K. BUCEY ; L. G. BURNARD ; F. BRADFORD ; G. H. TAYLOR.

Chairman : S. P. WOODLEY, M.B.E.

Manufacturing in the Aeronautic Age

by Boyd K. Bucey



Mr. Bucey, who is Assistant to the Vice-President — Manufacturing of the Boeing Airplane Company, Seattle, Washington, gained his commercial pilot's licence in 1928. While a student flyer, he earned the distinction of being the first pilot to fly "blind" on the Pacific Coast, and also the first pilot to carry out night flights.

He studied Air Transport in the Engineering School and graduated from the University of Washington in 1932, from the School of Business Administration, after which he joined the Boeing Airplane Company, where he spent three years in the various production shops. When it became apparent, owing to rapid expansion, that a separate tooling organisation was required, Mr. Bucey had demonstrated talents which resulted in his being given the prime responsibility for establishing the new department.

At the outbreak of the Second World War, he was in charge of all Boeing sub-contract work assigned to the automobile industry. His assignment was to train the industry in aircraft techniques and to become familiar with, and utilise, where practical, production methods of the automobile industry.

In 1942, he was appointed superintendent of all tooling in the Seattle area, and throughout the War years, was in complete charge of tooling for the Boeing B-17 Flying Fortress and B-29 Superfortress. After the War, he established Boeing's first Manufacturing Research and Development organisation, whose function was to investigate and perfect new production processes and techniques.

In his present position, it is Mr. Bucey's responsibility to ensure that his Company develops the manufacturing techniques required to meet the challenge of producing tomorrow's supersonic aircraft.

Since its establishment seven years ago, Mr. Bucey has also been very active in the Aircraft Industries Association, which is recognised as the voice of the aircraft industry, in America, in dealing with Government agencies. In addition, it serves as a focal point for the industries' interchange of manufacturing "know-how" and for the common resolution of mutual problems. He is also a member of the Society of Automotive Engineers.

RECENTLY economists have referred to our being in an Aeronautic Age, an age where business planning and economic theorising must be reviewed in the broad perspective of economic, political and military competition between the Soviet's and the Free World's systems. This competition has made aeronautics and the related electronics industry one of the main factors in establishing overall business trends. I am certain that no one connected with the aircraft industry would take violent exception to the effect this competition has had on the industry.

Not so long ago we joked about the Russians' Five-Year Plans; now it appears that they may have been more realistic in their long range planning than we in the Free World. The Russians' effective planning confronts us with a serious challenge. Before

discussing how the aircraft industry in the United States is meeting this challenge, let us see what is the environment of the Aeronautic Age.

An age of advances

It is an age of rapid and startling scientific and technological advances. In the United States some 5,000 laboratories are spending $7 billion a year on scientific and technical research. More than 200,000 professional scientists, aided by many times this number of skilled technicians, are conducting thousands of scientific experiments, while still other thousands are adapting the laboratory information to everyday use. For industry merely to keep informed is a major task. These advances are causing a trend to radically new weapon systems rather than gradual refinement of present models. Increasing complexity and long lead times dictate that improvements be made in large increments. This could mean going from a transonic bomber to one capable of speeds from Mach 3 to 5 with corresponding improvements in altitude, range and reliability, rather than merely to a Mach 1½ or 2 design.

The transition of the aircraft industry to this new environment is the most drastic and far reaching in its history, due not only to supersonic airplanes and increasing emphasis on missiles, but also to fiscal limitations.

Numerous manufacturing problems result from supersonic flight, such as those caused by aerodynamic heating and sonic vibration. The choice of materials is a complex, often perplexing decision, with steel and titanium presently taking the lead as airframe structural material. Conventional fasteners are giving way to spotwelding, brazing and fusion welding. Later we will be using super steels, molybdenum, glass, fused quartz, ceramics, cermets and high temperature plastics, with a need for still other production techniques.

Because of radically different materials, new machine tools are needed. The weight penalty of high strength materials requires ever closer tolerances in both tooling and fabrication, and such materials also require heat and increased pressure for accurate forming. New tooling techniques must be developed that are suitable for the reduced quantities and shortened lead time.

Watching the cost

Regarding the financial side of the transition, we have been living in a golden era of exciting advances with seemingly unending Government funds available. Now stringent funding policies in both our countries are complicating the design and manufacturing problems during the transition period. Accompanying the increasing effectiveness of new weapons is a corresponding cost increase of design, development and production. We must design and build in greater reliability and reduced maintenance to lower defence costs. Being a commercial enterprise we must develop a cost consciousness comparable to other industries. Cost will be a determining factor in selection of new weapons and companies to produce them.

To offset the debit or problem side of the ledger we believe there are many favourable factors. While satellites and missiles have had the headlines recently, we believe there is still a very important future for manned aircraft. Coupled with the expected healthy growth of the world's economy will be an even more rapid growth in air transportation, with continued demand for improved commercial aircraft. Indications are that commercial aircraft sales will average close to $1½ billion a year for the next 5 to 10 years.

Research for supersonic missiles and manned aircraft is virtually the same. Techniques and manufacturing problems are also quite similar, with missiles generally having fewer problems. Since missile development to date has been accomplished primarily by the builders of airplanes, it is safe to assume the aircraft industry will continue as the major producer of missiles. However, no one weapon is the solution to our defence needs. The flexibility of manned military aircraft gives it a decided advantage in coping with an enemy's change in type of war or defence tactics — to name only one, manned aircraft may be used to transport missiles closer to targets for increased accuracy. Therefore, we believe that manned military aircraft will continue to be produced for many years.

The aircraft industry has weathered previous technical, political and financial problems and the technically sound and efficiently managed companies will survive the present austerity period.

Learning to adjust

Having explored the new environment in which the aircraft industry must live, let us review some of the steps taken by its production people in the United States to adjust to this new era.

Virtually every one of these steps is aimed at strengthening management by better utilisation of the most important asset of any company — that is, its people — people of all ranks, from the head of a company to the person in the lowest paid job. These steps cover a wide range, from company reorganisation to a better method for sweeping the floor. Obviously, any one of the items that will be mentioned could by itself be the subject for a Paper; therefore, only a few of the more interesting will be covered.

One of the primary objectives of organisational planning has been to conserve and make more effective use of human resources. In view of the need for speed in our production process, the making of day-to-day decisions has been accelerated. Executives can no longer spend days conferring with specialists, departmental heads, etc. The authority to make and effectuate decisions has to be delegated to the lowest possible level. A dynamic line organisation with clear-cut and properly distributed functional responsibility

has become a necessity. In addition, the organisation must be flexible and able to adjust its operations to changing conditions to assure complete mastery of production at all times. This has been accomplished by the extensive use of decentralisation, coupled with limited and carefully selected centralised controls.

As the latest techniques are used in establishing the most effective type of organisation, so is an additional technique, known as Operations Research, used to evaluate the future trends in weapons and commercial aircraft from an economic, political, psychological and technical viewpoint. This technique also highlights areas of weakness in design or manufacturing "know-how", so that strengthening of such areas can be accomplished. All these techniques are necessary because today it is apt to be "one strike and you're out". Therefore, one wrong decision on which new product to develop can seriously affect a company's future. In addition, the whirlwind pace of technology is tending to force the military to seek more guidance from industry, which we must be prepared to give.

An effective management tool

Despite criticism of the use of committees, such as "the best committee is a committee of one", management has found that committees are a very effective tool of management. They are a logical way of overcoming some of the problems of size. Throughout industry we are emphasising the need for teamwork, that good management is the result of co-operative rather than of one individual's effort. Therefore, committees are being given more authority and responsibility, even in the making of major decisions.

More and more emphasis is being placed on the use of sound techniques in selecting people. Actual needs are critically analysed and interviews, tests, etc., are expertly conducted. Considerable emphasis is being placed on locating and developing the talent generally available within a company. Following the selection and hiring, there is a planned induction period of from a few weeks to many months which establishes the desired relationship and acceptance between the new person, his supervisor, the company, and other people with whom he will come in contact. While staff organisations can assist, this induction period must be primarily handled by the immediate superior of the new employee. Realising the advantage of developing supervisors from people having technical background, plus administrative and leadership capabilities, many companies are supplementing their shop-trained supervisors with college-educated personnel. This can be the supreme test of whether a company's integration techniques are effective.

Development or training is now recognised as a "must" for the survival of a company and has become a part of each company's long range plans and objectives. No longer can a company wait for people with skill or technological talent to "happen". Instead, they must make them happen.

The first step in establishing an effective development programme is a system whereby the person knows what his job is; this is generally accomplished by means of position descriptions. Next, he must know what is considered satisfactory performance and at regular intervals, be told whether or not he is meeting this standard of performance. If he is not, or if he is ready for advancement, a training programme, fitted to his needs, is worked out with him by his supervisor. This may include both "in-plant" and "out-of-plant" classes, job rotation, etc.

Although an organised formal training programme is the most universally used method of development, we do not lose sight of the fact that a supervisor's coaching will bring quicker and more positive results with less investment, provided the superiors have the time and ability adequately to coach their employees.

Frequently, failures that management consider are due to bad decisions were merely the result of poor internal communications. Much time and effort has been expended to develop communications that will effectively keep informed all levels of a company. Most aircraft companies find regular meetings the most popular means, with written communication and personal contact next in effectiveness. Nearly all publish company magazines or newspapers, or both. Communication pays off with better management, improved employer-employee relationships, and thus better utilisation of our human resources.

We recognise that each person is a social being who is motivated by factors other than money alone. While we cannot overlook the economic factor, it must be considered in connection with social motivation and incentive, such as pride in work well done and the desire for recognition and advancement. Job objectives are often used in place of controls permitting the use of initiative, which greatly increases the chance of quickly reaching production goals.

These basic principles and methods apply to the development of resources in the entire work force, from supervisor to janitor. We feel it is imperative that all levels of management understand and support the need, the potentials, and the techniques, of human resource development.

With the trend swinging toward fewer but vastly more effective weapons, improved reliability and maintainability becomes most important.

"High reliability"

"High reliability" is synonymous with "good management". Management must see that its people understand and accept reliability as everyone's job. Reliability must also be considered from a quantitative viewpoint, and as such, should and can be given the same consideration as performance, cost and delivery schedules.

Reliability has been best achieved by establishing controls, within the framework of existing line organisations, which control all phases of design development, test, production and the support of customer usage.

The trend toward overall weapons system development increases complexity and makes it mandatory that prime contractors place greater reliance on sub-contractors who specialise in equipment and techniques. In turn, these sub-contractors are expected to put greater emphasis on their research and development programmes, in order to keep pace with industry's needs. In the future it is very likely that a much larger proportion of a weapon system will be sub-contracted and, in many cases, the sub-contractor will be a company previously considered only as a prime contractor.

Symposia have proven to be a very effective means of communicating to the sub-contractors the industry's future requirements.

Solving common problems

All major airframe and engine builders and many major suppliers of aircraft equipment belong to the Aircraft Industries Association of America. The A.I.A. is concerned with industry-wide aspects of aircraft research, development and production. It attempts to work out co-operatively among its members, and with appropriate agencies and organisations, the solution to problems of common interest. The Manufacturing Committee of the A.I.A. has been greatly strengthened due to manufacturing's increased responsibilities and as a means of strengthening industry co-operation. Sub-committees have been established to improve the industry's tooling, conservation and testing methods and for more efficient machine equipment.

For example, as the complexity of weapon systems increases, there is a corresponding increase in complexity of test equipment. A sub-committee has been established to develop, through co-operative efforts, an individual and industry-wide understanding of manufacturing test equipment problems. The committee is also developing standards for test equipment. While the main emphasis has been on electrical test equipment, other systems such as hydraulic, pneumatic, etc., are also included.

Realising the challenge facing the aircraft industry, technical societies are assisting in the free interchange of ideas, developments and techniques by symposia, forums and technical papers. They also develop and publish many standards. Educational and technical institutions are making vital contributions in the fields of basic and applied research. Frequently they serve as the media for the collection and dissemination of information. The Battelle Memorial Institute is the central agency for all information relative to the production and the use of titanium and its alloys.

Quality control

We have quickly covered such items as delegation, incentives, development, communication, etc. Now let us see how this emphasis by manufacturing to develop to the maximum the potential ability that is in each individual, and thus in each department of a company, has improved a few of the functions.

As a result of this approach, the basic function of inspection has been replaced by a broader, more effective one known as Quality Control. Formerly inspection was the responsibility of only one department; now quality control is the responsibility of everyone and involves nearly every operation in the plant. It applies not only to production of parts, but also to design, planning, method study, procurement, etc., since all these can affect the acceptability of the end product.

One technique of quality control is the establishment of quality levels or standards of performance that we wish to maintain and repeat. Besides their obvious use in control of production, these quality levels are used in other areas — for example : quality level charts are used in tool storage where tools can be lost due to errors in recording or storage. In either case, the lost tool can seriously affect production schedules. Periodically a sampling is taken of the total postings to ascertain the percentage of errors. When the number of errors becomes excessive corrective action is taken to bring the operation back to the established quality level.

We all know that the quality level of end products never exceeds the capabilities of the machine equipment used in production. In order to maintain machine capabilities it is necessary to control machine wear, loading, lubrication, etc. Most maintenance departments now accomplish machine maintenance with the aid of quality check lists. With sufficient data, adequately analysed, it is possible to pre-plan maintenance schedules to prevent down-time as a result of equipment failure, illustrating how the maintenance department's quality control works for it.

Vendor rating systems

Vendor rating systems, another application of quality levels, are used to show the performance of vendors and sub-contractors on a day-to-day basis. From this rating corrective action can be taken or the source discontinued for a better one.

The lead time necessary to develop a new airplane or missile is being shortened by anticipating the manufacturing problems while the new product is still in the preliminary design stage. Most companies now have organisations — most frequently known as Manufacturing Research — whose prime responsibilities are fully to appreciate design and operational requirements and to develop, quickly and economically, the production "know-how", tools and equipment to meet the design requirements. These units gear their operation to both immediate and long range plans, plus maintaining a flexibility to adjust to changing conditions. They are often given a degree of freedom which permits them to delve into production problems so that better methods, increased reliability, etc., may result. A systematic and analytical approach is used on all production problems. Therefore, these groups are staffed with mathematicians, scientists, engineers and technicians.

New production techniques

In describing some of the more interesting production techniques, tooling methods and equipment that are being developed in the United States, this discussion will be restricted to those used to produce weapons in the speed range up to Mach 5. Just as there is no complete agreement among design engineers as to the best material or type of design, so there are differences of opinion as to what are the most suitable production techniques. While I will present the new methods in the order in which they normally occur in the manufacturing sequence, included are techniques which sometimes apply to building the conventional aluminium aircraft and at other times are used in the construction of weapons fabricated from heat-resistant materials.

Cutting is one of the first operations in aircraft construction. Metal sheets, strips or plates must be cut very accurately into individual pieces not only to prevent waste, but to reduce assembly time and provide the essential aerodynamic smoothness. Some of the major developments in metal sheet cutting are friction saws, portable skin saws, inexpensive blanking dies, and the profile trimming of high strength heat-resistant material by spindle shaping.

Friction sawing

Friction sawing of titanium alloys and stainless steel is becoming common. It is cheaper and faster than cutting with toothed saws and causes but slight burring. Friction saws are normally run at between 4,500 and 6,500 surface feet per minute. Remarkable results have been achieved in sawing titanium alloys with blades which have been 50% abraded.

The portable skin saw is very similar to the portable electric saw commonly found in home workshops. A 6 in. blade with two carbide inserts is driven by an air motor at 10,000 r.p.m. The saw cuts aluminium up to 1 in. thick and is excellent for cutting plates fastened to an understructure, since the depth of cut can be preset, thus guarding against damage to the understructure.

"Cookie cutter" dies

Recent developments in dinking or "cookie cutter" dies for sheet metal blanking or piercing are worthy of consideration. This type of die, made by a newly patented technique, costs about one-tenth that of a conventional die. It has the capability of blanking thousands of parts from 4130 steel in thicknesses up to $\frac{1}{4}$ in.

Spindle shapers using 1 in. diameter or larger carbide insert type of cutters, and provided with CO_2 as a coolant, are successfully being used in production to trim heavy gauge stainless steel and titanium alloy parts. Obviously, rigidity of cutter, tool and part are essential for successful operation; 800 SFM is generally used for titanium and 1600 SFM for stainless steels.

There has been a decided shift toward the use of methods and techniques whereby extensive machining or large metal removal is not needed. This is done through the use of precision forgings, forming and other chipless techniques that reduce machining time and operations as well as conserving the cost of expensive materials.

Large forging presses

You are probably all aware of the United States Air Force's Large Forging Press Programme, which resulted in the building and installation of one 50,000-ton press and one 35,000-ton press. These large modern presses make it possible not only to produce larger forgings, but forgings with thinner webs and closer tolerances, which reduces machining. More recently the draftless type of forging has been developed, which further reduces the amount of machining required, and also makes it possible to produce forgings having mechanical properties that in many cases could not be made by conventional forging methods. On large components where the forging is used as a space frame, a good portion of the structure can be forged to close enough tolerances to reduce drastically the machining requirement. Chip losses have been as low as 35% by weight on forgings used in large bombers and commercial planes; however, this experience is not true on smaller aircraft, such as fighters and interceptors, and smaller components of large aircraft. Difficulty is still encountered in obtaining forgings with thin enough web flanges on these parts and chip loss is as high as 70% to 80%. Progress is being made, but we still need closer tolerances on dimensions and straightness of parts, thinner sections to minimise machining, reduced lead time, and more and larger no-draft forgings.

Steel and titanium forging

The steel and titanium forging picture is not favourable and usage is very limited, since in general the sizes available are too small, the tolerances and thicknesses too large, and the strength properties inconsistent.

Stiffened skins once required the assembling and fastening of separate stiffeners to the skin. Now the metal industry has developed tools and techniques for extruding large, stretcher-levelled, integrally-stiffened lengths suitable for airplane components. As yet, these extrusions are not straight or true enough to be incorporated directly into the airplane. In addition they frequently must be machined to a taper. However, with the use of integral construction weight has been reduced approximately 25% with even higher cost savings. On one large jet bomber over 900 lb. was saved by using integrally-stiffened wing skins.

There are other methods of reducing machining, such as the use of precision high strength castings and impact extrusions. However, I frankly feel that

relatively little progress has been made in developing these two techniques to their full potential.

Despite the urgent need for less machining, the amount of machining required on a high performance airplane continues to increase. This is due to greater use of large components, plus the ever-increasing weight problem. Engineering is requiring ever-closer machine tolerances, since closer tolerances result in less airplane or missile weight with a resulting increase in performance. Each excessive .001 in. in thickness adds .0144 lb. per sq. ft. for aluminium alloys and .0413 lb. for steel.

Weapons built for speeds of Mach 3 to 4 will very likely use steel for their aerodynamic surfaces. Therefore, excessive tolerances on skin material can result in a staggering increase in weight. It would be possible for a bomber having 2,000 sq. ft. of wing area to increase its weight by approximately 5,000 lb. if the skin material were on the high side of the tolerance. This could mean a 50,000 lb. increase in weapon weight to cover the extra power plant, fuel and structure required to fly the additional 5,000 lb.

Better machining techniques

The trend toward use of high tensile materials in the range of 180,000 to 320,000 p.s.i. has required the development of better machining techniques. In general, higher horsepower, more rigid machines, tool holders and work-holding equipment are required. In general, old machines will have to be replaced by new higher horsepower, more rigid machines; new tougher cutting tools will have to be developed; and design criteria will have to be established for more rigid machine fixtures. To meet this need, and to get a better understanding between the user and the machine tool builder, the Aircraft Industries Association established an Equipment Committee. This Committee has determined the industry's machine requirements for conventional milling machines, spar mills, skin mills and stretch presses, has issued standards for these requirements, and has worked with the machine tool builders to see that the required equipment became available. As a typical example, the industry standardised on a horizontal knee mill, known as NAS 909. This new knee mill has four times the horsepower of the previously available mill plus greater rigidity, plus faster loading features, and as a result it is producing the same quantity of parts in two hours that were produced by the old type mill in 16 hours.

Techniques are being developed for obtaining improved cutter life in the new materials (i.e. to incorporate the use of pre-formed carbide inserts, sandwich brazing and better grinding practices for milling cutters).

Numerical control

This Equipment Committee has also been very active in determining the advantages, problems, availability, standardisation and application of numerical control in the aircraft industry. These studies predicted, and it has since been confirmed in production, that the use of numerically controlled equipment would reduce manual office paper work by 66%, data processing by 98% and machining by 65%. This method virtually guarantees uniformity of parts; one might say that quality control is built into the machine. The finished part is exactly as desired by the design engineer, since there is no interpretation of the design by machine operators.

Numerical control tools and holding fixtures are simpler and tapes can be quickly and economically revised. Obviously, there is less labour per part, resulting in a much higher output per machine. Further, there is no cost of re-training skilled tool operators when engineering changes are made, as revised tapes are the only requirement. There will be fewer scrapped parts resulting from errors of machine operators. Approximately 350 companies are doing developmental work on numerical control systems and data processing. The United States Air Force has already let about $20 million worth of contracts for development and production of numerically controlled production tools and modification of equipment. The extent of numerical control application obviously depends upon the size and complexity of the product, and on the cost of the numerically controlled equipment. Milling machines top the list for use of numerical controls, particularly skin mills and milling machines for various types of contour milling or large complex shapes. The next most probable use of numerical controls will be at the other extreme — machine tools such as boring mills, jig borers, drill presses, etc. These machines require comparatively simple and inexpensive types of controls.

Chemical milling

Two years ago chemical milling was practically unknown. Today it is a large industry with an almost unlimited future. Besides its advantages for shallow sculpturing, tapering and for closely controlling the thickness tolerance of sheets, it is also being considered as a means of machining parts to a closer dimension than is possible by normal machining methods. Forgings and other parts will be machined to an overall dimension somewhat larger than that specified and then chemically milled all over to the blueprint dimension. This eliminates some of the warping problem and it removes the limitation on minimum web thickness. Stainless steel is continuing to gain in production importance in the chemical milling industry. To date production work has been predominantly 17-7PH. The austenitic steels (i.e. 300 series) also can be chemically milled very satisfactorily. The non-stainless types, such as 4130, 4140, 4330, etc., show promise, but are somewhat erratic in their chemical milling characteristics. Inconel X is fair, but all of the super alloys need further developmental work before they can be chemically milled.

Titanium alloys are susceptible to hydrogen pick-ups with resulting embrittlement. Since both cleaning and chemical milling may increase hydrogen concentration, it is important that one start with as low a hydrogen contamination as possible. Generally, if

the contamination at the start of the chemical milling operation is less than 100 parts per million, an acceptable part will be produced. Fortunately, a number of titanium alloys are being produced with a maximum pickup of about 70 to 100 parts per million.

Returning again to the critical weight problem, the physical limitations of mills presently producing thermal resistant materials, generally forces the tolerances to the heavy side. While chemical milling the sheets is one means of controlling this tolerance, another is the use of abrasive belt grinding of the sheet and plate prior to its use for skins or detail parts. Most of the generally used heat-resistant materials have been successfully abrasive belt ground, such as 17-7PH, 17-4PH and Inconel X, and titanium alloys. Thicknesses from .013 in. up to 1 in. have been abrasive ground; as an example, 1-in. thick 17-4PH plate has been ground to a tolerance of $\pm$ .003 in.

To a limited degree, electrolytic etching and spark-arc or electro-discharge methods are being used to reduce metallurgical damage from machining or to solve tool problems. Considerable cost reduction has been achieved by standardising drills and reamers. This was a joint accomplishment of the Aircraft Industries Association and small tool producers. Another example of co-operative development is a portable air operated drill which is self-holding, self-feeding and self-indexing, thus eliminating the need for costly drill blades. The production potentials of using carbide drilling and reaming tools is just beginning to be recognised and the necessary tooling and equipment techniques developed.

Improved forming techniques

Improved forming techniques have been developed to cope with more complex three-dimensional shapes, higher strength and heavier gauge materials and more critical aerodynamic requirements. Many of the new forming techniques use a method whereby the material is stretched beyond its yield point. This produces stable and accurate parts which can be used in sub or final assembly with little or no hand rework, trimming or shimming being required.

Rubber forming is probably the most economical forming method used in the aircraft industry. It has been greatly improved in recent years by increasing the pressures from a low of 1,000 p.s.i. for pre-war strength materials to 5,000 p.s.i. and over for use in forming the new high strength materials such as 78-S aluminium, titanium, high strength steels and magnesium. Several methods of rubber forming have been developed to make more effective use of the increased pressures required.

A recent development in metal forming is that of impact forming with a trapped rubber head. Instead of a costly hydropress for applying pressure in the neighbourhood of 10,000 p.s.i., drop hammers with rubber retaining heads are used to apply the equivalent pressures. An impact drop hammer has been designed which includes two conveyors feeding work into the hammer. One conveyor runs through a furnace to heat the tool and parts for hot forming. The other conveyor remains at room temperature for conventional cold forming. During the hot forming cycle the tool and part are in contact with the rubber for so short a time that the part does not cool off appreciably, nor is the rubber damaged. Parts are thus hammer formed with greater speed and accuracy than previous methods would allow.

Explosive forming

Another variation of impact forming that is just coming out of the laboratory stage is the use of explosive forming. Shot gun shells are enclosed in a specially designed die to provide power for making small to medium size, yet relatively deep and complex draws, or dimpled holes in some of the tougher steel and titanium alloys. Shaped or controlled charges are used and can be handled and used safely. Another approach is the use of two ram actuated dies which move in a horizontal plane delivering simultaneous blows to a blank positioned vertically between the two dies.

New power spinning equipment combines the features of a normal spinning lathe with that of a wall forging technique. The force used for spinning and forging is applied by cam or numerically controlled hydraulically actuated rollers. High strength sheet materials can be formed into parabolic, conic, hemispheric and other shapes from one single piece.

New larger and heavier stretch forming equipment is being used throughout the industry. Most of the new equipment has special yield and tension controls which determine the correct tonnage required to form each part and assures that the exact force is applied to subsequent parts. Thus very precise tolerances can be obtained during production runs. While discussing stretch forming equipment, it might be interesting to note that one of the large producers of aluminium plate will soon be installing a 30 million pound plate stretcher, which is double the power of the largest stretcher now in use. The advantages of using stretcher-levelled plate are known to all of you.

Use of heat in metal forming

Heat is used extensively as an aid in metal forming, since it temporarily reduces the yield and ultimate strength of the material. Because the temperatures for forming titanium alloys are so much higher, that is, from 1000°F to 1500°F, new heat sources had to be developed. Tools and parts are generally heated in production by three methods — gas, electric heating elements, and through electrical resistance. Gas is usually pre-mixed with air by a combustion controller or small venturi mixers. The gas may be fired inside the tool or applied to the outside of the tools and parts by ribbon type burners. For manual control a temperature indicating paint is used. Automatic control uses a radiamatic (infra-red) head to indicate and control the temperature. The gas heating method

has also been applied to progressive rolls for forming titanium alloy sections. An encircling furnace surrounds each of the rolls; a common manifold feeds the burners and a standard combustion supplies the air-gas mixture. Water cooling is used to control the temperature of the roll shafts and machine proper.

While electrical element heating is not new, new techniques in wiring, element placing and control have made this method practical for heating temperatures in the 1000°F - 1500°F range. When rectangular blanks are used the parts can be resistance heated for either hammer forming or conventional press forming methods.

Forming by shot peening

Forming by shot peening is a new cold working process accomplished by striking the surface of the metal parts with spherical shot. Each shot acts like a tiny ball peen hammer, making a dent in the material and stretching that surface. By varying the intensity with which the shot strikes the surface and the speed with which the nozzles travel over the surface, simple shapes can be produced quickly and accurately from large sheets of material. These machines are now being used in production to form large integrally stiffened wing panels to wing contours.

Heat treatment of 6AL-4V titanium alloy is a two-stage operation. Solution heat treatment at 1700°F for 10 minutes, followed by an immediate water quench, is the first stage. Aging at 1000°F for four hours yields additional increased mechanical strength and physical stability.

Titanium alloys have a great affinity for absorption of gaseous elements such as hydrogen, oxygen and nitrogen at elevated temperatures. Protecting the material from such contamination during solution treatment at 1700°F is mandatory. This is being accomplished at present by the application of protective coatings prior to heat treatment. A heat-resistant silicone base aluminium paint properly applied, air dried and baked at 1250°F, has been used extensively. Special ceramic coatings have been developed which are more practical for production purposes.

A measurable amount of surface oxygen embrittlement results even with use of these protective coatings. This embrittlement must be removed. Removal is accomplished by chemical milling in a pickling solution of nitric-hydrofluoric acid. The average thickness removed is .003 in. per surface, or .006 in. total gauge reduction.

Severe warpage results from water quenching in the first stage solution treatment of most light gauge sheet and formed parts. Re-sizing or re-forming these parts is accomplished by aging at 1000°F in restraining matched die type fixtures. Warpage is removed by the combined action of creep and stress relief at the aging temperature while confined in the fixture for the time required to complete the aging cycle. No atmosphere protection is necessary during aging and stress relief operations.

Aircraft companies are making increased use of the standardisation and documentation of tooling and manufacturing processes to reduce costs and the lead time required to tool up for new models. The idea of standardisation of scaffolding or work platforms had until recently been overlooked. By standardisation of scaffolding design, one aircraft company recently saved nearly $400,000 in tooling up for a large airplane.

Less use is being made of massive, structurally rigid master gauges. Instead the trend is toward the use of simple plate type gauges that are positioned by means of lines of sight (optical tooling) and spaced station-wise by inside micrometers or length bars. It is believed this new system of gauging is as accurate, if not more so, than the former large one-piece gauges and is much more economical, particularly where a small number of planes are to be produced and high tooling costs cannot be justified. We have the British to thank for developing the basic instruments we use in optical tooling. Many improvements have been made in precision telescopes, targets, planisers and accessories, along with the use of closed circuit television sets to enlarge the image for greater accuracy.

Reinforced concrete is beginning to replace steel for large jig bases. Its stability, availability, low cost and reduced jig erection time more than outweigh any of its unfavourable characteristics.

With the advent of the larger jigs required for bomber and large transport production the expansion differences betwen steel and aluminium became a critical consideration. Aluminium is now used extensively in jigs over 35 ft. in length to reduce the difference in expansion of the tool and the part.

Development of new materials

New materials are being developed to replace Kirksite, lead, cast iron and other expensive materials currently used for form dies. General Motors has recently developed a die material that gives a die life between that of conventional zinc based tools and ferrous dies. Nickel and titanium alloys in a soft zinc matrix form hard particles which give this material its wear resistance.

Aircraft manufacturers are increasing the use of plastic materials for tooling as a means of slashing production costs. Five years ago one company had only one tooling engineer and one shop man working part-time on the development of plastic tools. Today this company has over 250 employees making plastic tools. Generally the polyester and phenolic resins have been replaced by epoxy resins.

Due to design problems caused by sonic vibration, temperature, and the effect of weight on supersonic planes, we are being forced back to the old "bits and pieces" type of construction. Therefore, it is imperative that these "bits and pieces" be joined by the most efficient and reliable means. The most

common joining methods currently used are adhesives, brazing, fusion welding and spot welding.

The primary advantage of adhesive bonding is the simplicity of the process. Satisfactory bonding is achieved at low temperature which reduces the possibility of warpage or change in the properties of the material. Dissimilar metals can also be joined by this process, automatically providing a safeguard against any galvanic corrosion. Improvements in cutters, machines, and the use of freeze chucking have eliminated the need for stabilising honeycomb core when machining. While many types of bonding facilities have been used in the past, it appears that autoclaves are now almost universally accepted as being the most flexible, reliable and efficient. With supersonic flight the main problem is to develop adhesive films that will withstand the ever-increasing temperatures. New adhesives are being developed both in the United States and England which show promise of at least 50% of room temperature shear strength when operating at temperatures up to 650°F.

For higher temperatures, other methods such as welding or brazing will probably be used. Stainless steel sandwich panels are ideally suited to high performance aircraft, as the weight-to-strength ratio of the sandwich panel is high compared to either the skin stiffener construction or solid plates. The panels have excellent fatigue characteristics, rigidity, and aerodynamic smoothness of the completed assembly. To these advantages must be added that of their insulating qualities, particularly when used for a fuel compartment. Joining by brazing appears to be the answer to the fabrication of most types of stainless steel and titanium sandwich panels. There are still several production problems which must be solved before the method becomes entirely economical. Normally the process must be carried out in areas where a high degree of cleanliness, correct humidity and filtered air can be maintained. Radiographic inspection is the most generally accepted method of inspecting the completed assembly. Plans are under way to develop the technique further and to develop and acquire large scale facilities which should help in solving the many production problems.

Resistance welding

A development of new configurations for minimum weight structures joined by resistance welding is under way. It is expected that the new configurations will demonstrate that resistance welding affords maximum advantages for joining both titanium and steel structures at production costs which approximate current manufacturing costs of aluminium structures. Advantages of resistance welding are the relatively low cost of facilities, use of conventional type tools and fixtures, pre-heat treated details, and application of current quality techniques to this new method.

New titanium alloys that oxidise rapidly at high temperatures were at first welded while entirely submersed in an inert atmosphere. Trailing gas shields have been developed that can be attached to the welding torches, and these, along with similar trailing or channel type fixed shields located under the weld bead, provide complete protection.

Controls have been developed to mechanise welding which enables programming of major weld variables, such as arc volts, arc amperage, carriage travel speed and filler wire feed rate. The programming consists of controlling the magnitude and the time of each major welding variable during the start, configuration and end of the weld. This programming enables control of penetration at the weld start, penetration on variable material thickness, arc crater and/or cracks at the end of welds.

Automatic hot squeezer riveters are now available for driving titanium rivets. This machine has a yield temperature sensing control which drives the rivet automatically when the correct heat has been reached.

New method of producing radomes

A new method of producing fibreglass reinforced plastic radomes has been developed. The process consists of mechanically wrapping resin-impregnated fibreglass rovings about a tapered mandrel in alternate circumferential and longitudinal layers and then curing. This technique produces a radome having an electrical tolerance of $\pm$ 1° IPD. Previous methods produced radomes having electrical imperfections requiring costly electrical corrections by adding glass tape segments to the interior of the radome. The time required to produce radomes by the new technique has been substantially reduced.

Another significant item is the use of ultrasonics, magnetic techniques and radioactivity to inspect for characteristics that heretofore were determined only by destructive means. Ultrasonics is probably showing the greatest potential. It detects flaws in steel parts that previously defied detection when using the largest X-ray equipment. Ultrasonics can also be used to check weld qualities.

Effective methods have been developed properly to introduce new manufacturing techniques and processes into production. They are based on the desirability and need to inform and to get concurrence from all organisations, both directly and indirectly concerned with the new process. One method, of particular advantage when the new process is complex, or when operator skill is important, or where there is no similarity to existing processes, involves having factory personnel working in the factory area first use the new method on a small scale and with technical assistance. From this experience, the proper amount of documentation can be determined and the final formal and informal training programmes developed.

Meeting the challenge

Thus the aircraft industry in the United States views the problems of the Aeronautic Age, and is striving to meet the challenge by improvements in organisation, skills, techniques and facilities. This is not the first time the industry has had to cope

with a changing national budget picture, a sudden awareness of the military power of our adversaries, changes in international relationships, or major improvements in military weapons. However, a relatively new factor is the accelerating pace of scientific and technological progress resulting in drastically increased weapon complexity. This complexity is a fact we must live with, and it is virtually the same, whether the weapons are manned or unmanned. It is reasonable to expect that the industry which brought the airplane to its present advanced stage should continue to develop and produce missiles most efficiently and at the lowest overall cost.

Despite the present publicity regarding satellites and missiles, we firmly believe that manned airplanes will be the backbone of our Air Forces for many years to come. Additional commercial aircraft are also required, since it is doubtful that any major airline can afford not to go all out for jet aircraft.

This period of adjustment differs from previous ones in that management competence, the ability realistically to plan and develop the skills and "know-how" to produce the weapons efficiently, is becoming of equal if not greater importance than engineering competence.

Since the aircraft industry carries the major share of the defence effort, and intends to continue doing so, it is necessary that we make these adjustments to the environment of the Aeronautic Age.

REPORT

Chairman : THE RT. HON. THE EARL OF HALSBURY, F.R.I.C., F.Inst.P., M.I.Prod.E., President of the Institution.

THE Chairman said he was sure it would be the wish of all those who were members of The Institution of Production Engineers that in declaring the Conference open, he should extend a very hearty welcome to all those visiting the Conference, particularly those who had taken the trouble to come a very long way.

Secondly, he expressed the Institution's appreciation to the University of Southampton for making it possible to hold the Conference on their campus.

Thirdly, he extended, on behalf of those present, thanks and congratulations to the Chairman of the Southampton Section and his Committee for the local initiative which had convened the Conference and called it into being.

The Conference had started some years ago simply as a piece of local initiative, and it had now become a recognised national annual Conference. Its success was such that it had encouraged the Institution to earmark the giving of the Lord Sempill Paper for this occasion. Lord Sempill was himself an engineer. He was apprenticed to Rolls-Royce and when he served his time in 1908, he was working on problems connected with the very early aircraft of those times. Those whose memories ran back as far as that were becoming rather few on the ground and it was pleasant to know that one of the early pioneers — Lord Sempill — had been an enthusiastic member of the Institution almost from its foundation, and had been one of the very distinguished holders of the Presidential office.

It was in recognition of his many services to the Institution that the Lord Sempill Paper had been established, and the Conference was privileged to have as this year's speaker Mr. Boyd K. Bucey, who had chosen as his subject "Manufacturing in the Aeronautic Age".

Before presenting his Paper (which appears on pages 129 - 138), Mr. Bucey said he wished to express his sincere appreciation of the privilege and honour of speaking on this occasion. He had looked forward for quite a while, with great anticipation, to getting better acquainted with the leaders of the British aircraft industry.

In describing what the aircraft industry in the United States was doing to meet the very complex and rapidly changing conditions encountered today, he would make no attempt to draw any comparison between American and British methods, because unfortunately he was rather unfamiliar with British methods. He hoped, following the Conference, to visit many British firms, and thus to get better acquainted with their methods. It was possible, therefore, that he would describe some new American methods, when the British aircraft industry had already developed even better ones. He was already aware of several cases where this was true.

He thought The Institution of Production Engineers was doing a wonderful job. It was something which was definitely needed in the United States, where there was no such organisation to promote the science and practice of production engineering. To a limited extent, it was done by the Society of Automotive Engineers and the American Society of Engineers, but nothing was done to promote prestige through the use of examinations.

He wanted particularly to say that in his opinion the British trade journals did an outstanding job in presenting technical developments around the world. He much preferred to read the British rather than the American journals. He learned a great deal more from them.

Mr. Bucey then presented his Paper, which was followed by a colour sound film illustrating some of the production methods which would be used in the United States in the near future for building supersonic large manned aircraft, with a speed range about Mach 3 and with potentials of Mach 5.

In thanking Mr. Bucey for his extremely interesting Paper, and for coming such a long way to present it, the Chairman expressed pleasure that Lord Sempill had been able to attend this Session of the Conference.

MANUFACTURING PRACTICE

A Review of British Aircraft Industry

by L. G. Burnard

M.I.Prod.E. A.F.R.Ae.S.

1. Introduction

ANY attempt merely to outline manufacturing practices in the British aircraft industry is, in itself, a task of some immensity. It is, in fact, not possible in this Paper to do much more than consider the most interesting of recent developments but, in order to broaden the scope, leading airframe manufacturers have been approached to contribute particulars of any new developments they consider will be of interest to the Conference. Their response has been most helpful, and I would like here to acknowledge my gratitude for their ready generosity.

Consideration of the aircraft industry should not, of course, exclude the engine manufacturers. That any reference to their work has been excluded is due entirely to the inadequacy of my knowledge, but I would like to suggest it as a future subject for presentation by someone better qualified than myself.

During the past decade, the whole aspect of manufacturing practice in the airframe industry has undergone, and is still in the process of, radical change. At the end of the Second World War, aircraft were constructed mainly from sheet metal with little machining requirement except for large items such as spars, but of recent years many firms have adopted integration as a design philosophy, involving the machining of large slabs of light alloy. The workshop emphasis has accordingly changed from the fitting to the machine shop, where the milling function is now predominant.

This change has brought new problems which require the adoption of new techniques, some of which are metallurgical—for example, the use of stretched slab to obviate distortion during machining operations, and the trend is likely to continue if military aircraft are to be built to fly at higher Mach. numbers. Further development will inevitably require the manipulation and machining of higher strength materials, such as titanium, stainless and very high strength steels, as well as new techniques to permit the fabrication of stainless steel honeycomb structures for such vehicles as missiles and rockets.

Higher speeds demand increasing complexity of systems and a multiplication of the parts which must be housed within the airframe and whilst the problem is less pronounced in the case of civil aircraft, even here there is an extending requirement for more machining in the form of stiffened wing planks, integral fuel tanks, machined ribs and frames. The problem is intensified with rockets and missiles where the density of installed equipment is very high.

For these reasons, it is important, therefore first to discuss developments in machining practice.

2. Machining

2.1 Routing

When the design of large integrated components first began to make its appearance about seven or eight years ago, the immediate reaction was to produce these items on existing copy milling machines

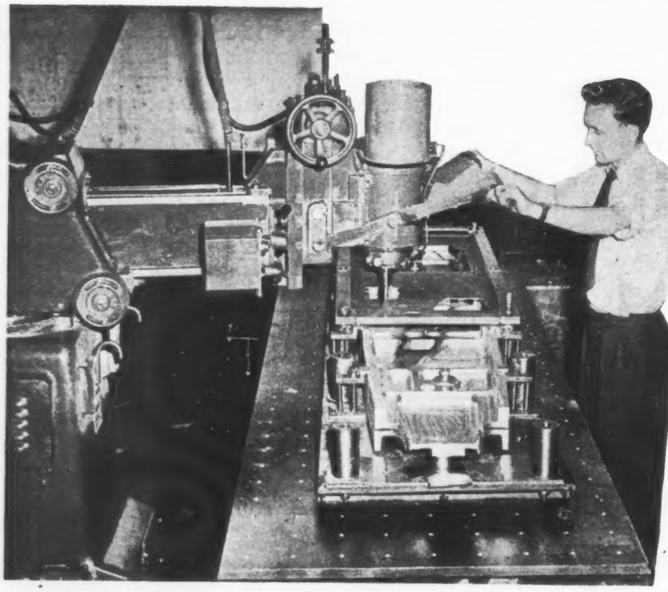


Fig. 1. Radial arm router

(Vickers-Armstrongs (Aircraft) Ltd.)

such as Hydrotels, Kellers, Rigid mills, etc. It was soon realised that these machines had their limitations, mainly because of low cutter speeds. Attention was then turned to the possibility of using heavy duty routers to produce the components. This process is now well developed, and quite large complicated components are produced by the routing method, with a saving in time over the copy mills of perhaps 200 per cent. or more. The early machines were merely adaptations of radial arm routers, but these have now been stiffened up and specially designed for the purpose.

The routing technique has also received a degree of sophistication in so far as programmed numerical control is now envisaged for some of these machines. Servo and hydraulic operation have also been applied.

One of the attractive features of the copying technique is the simplicity of the tooling. A fixture to hold the component in its correct relationship and a series of templates to control the various machining operations, are basically all that is necessary.

Figure 1 shows a radial arm router which has a cutting head of 12 h.p. running at 12,000 r.p.m. The radial arm has been deepened and its bearings stiffened up so that an accuracy over the bed area of 6 ft. by 2 ft. 6 in. is better than ·004 in. This is quite sufficient for most of the components, as the average inaccuracy over the small pockets which compose the integrated components will be proportionately a great deal better. With this type of machine, the component is located by means of accurate tooling holes on a heavy base plate. The base plate has mounted on it pillars which are accurately positioned and carry bushed holes. It is now possible to apply a series of templates to the fixture, locating them on the pillars by means of the bushed holes. With accurately made templates the relationship of the pockets and cut-outs one to the other, overall profiles, thicknesses of flange, etc., can be controlled well within drawing limits. These drawing limits vary from company to company, but generally are in the region of —·005 in.+·010 in.

Vertical control of web thicknesses can be more accurate, being determined by barrel stops and dial indicators, so that a predetermined setting can be repeated in production.

2.2 Overhead template routers

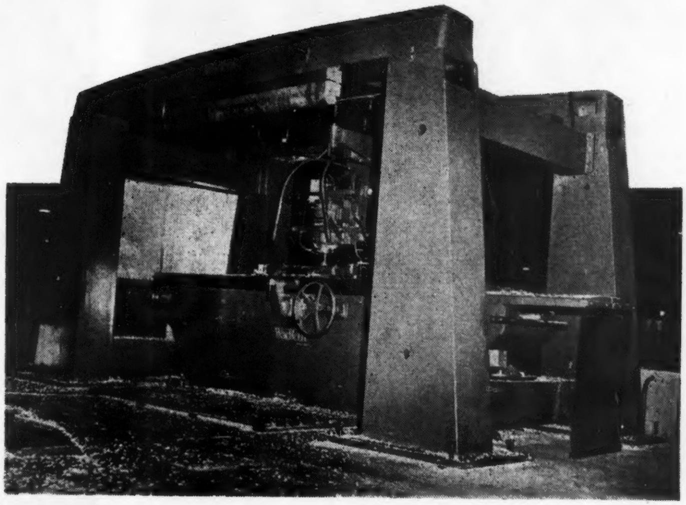
The early machines described in 2.1 have the disadvantage that it is necessary to remove the template in order to change the workpiece. Machines are therefore built with a structure which carries the template overhead, as shown in Figure 2. The table of

Mr. Burnard completed a general engineering apprenticeship in Bristol and entered the aircraft industry in 1928, in the engine division of the Bristol Aircraft Company. He joined Aero-Engines of Kingswood, as a planning engineer, some time before the War. He went subsequently to Phillips & Powis of Reading, and was appointed Chief Planning Engineer of their shadow factory at South Marston. He remained in this position throughout the War, being responsible for the various types of Miles Master aircraft and later, various marks of Spitfire.

The factory being taken over by Vickers-Armstrongs (Aircraft) Limited after the War, he was appointed Chief Development Engineer, and is now Assistant to the General Manager.

Fig. 2. Overhead template router

(Vickers-Armstrongs (Aircraft) Ltd.)



the machine and the template holder are jig drilled with a pattern of holes bearing accurate relationship one to the other, so that it is possible to place a locating fixture on the bed, and templates on the template structure overhead, which are in correct relationship to each other, without further setting.

There are three main types of these machines. One of these has the pillar carrying the swivelling arm mounted on a slideway system, so that the work portion of the machine can be traversed to cover the area of the fixed bed. With these machines it is possible to build up a machine covering almost unlimited length.

The second has a sliding table. This is particularly adaptable where integral stiffeners have to be milled into skins in the transverse direction to the table. With a template controlling one stiffener position mounted overhead, the workhead can be traversed across the table, machine a stiffener and return to its start. The table is then indexed along to a new position and afresh stiffener machined. Thus, by incremental progress of the table along the bed of the machine, the whole of the stiffening network can be accommodated. By the use of various index plates mounted on the front of the table, any pattern or width of stiffener can be catered for with only one template.

The last type is one with a fixed head and a fixed table for normal copying work. With all these machines heavy cuts can be taken, and the operator finds it easy to control the movement of the cutter. Due to the high rotational speeds, tooth loads are low and little effort is necessary on the part of the operator to machine even heavy cuts. Heads of 20 h.p. are now available to enable very heavy roughing cuts to be taken .and the head is fully under control of the operator even at these powers. The cutters used are made with inserted tungsten carbide blades. The number of cutting teeth is generally two. For wide cuts in profiling the external peripheries of components, spiral cutters are used with inserted carbide blades. It has been found essential on all routers to use a draw bar and mild steel cutter bodies fitting directly into the cutter spindle. Cutters held in draw bar collets are completely unsatisfactory as they pull down into the work. Spray mist lubrication is used, not for cooling purposes, but in order to prevent cutter smear. With spray mist lubrication, it will be found that cutter life between re-grinds is two or three times greater than if the cutter is allowed to run dry.

2.3 Link arm routers

In this machine, Figure 3, the arm bearing the cutter is articulated. On the column it runs in heavy bearings spaced widely apart. The knee also is carried in heavy bearings. This type of machine has less deflection and less friction than the earlier radial arm routers. Over a perfectly flat surface table, the total deflection on an area 7 ft. by 3 ft. is less than ·003 in.

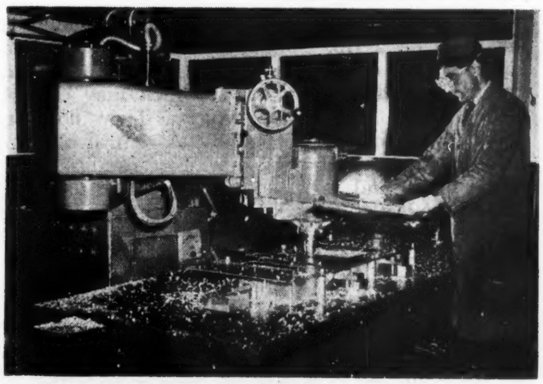


Fig. 3. Link arm Wadkin router

(Vickers-Armstrongs (Aircraft) Ltd.)

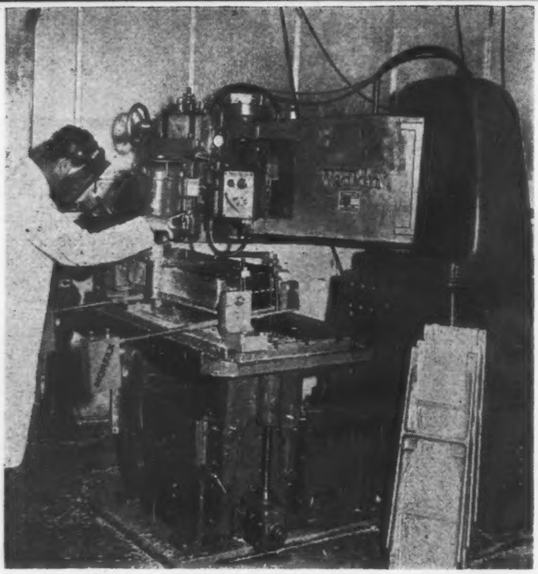


Fig. 4. Machining variable bevels on a link arm Wadkin router (Morfax Ltd.)

Link arm routers can be supplied with overhead template carriers, but are more generally used with templates fixed directly over the workpiece, using standard guide bushes to trace around the cutting area. With vacuum chucks on the work tables, the sculpturing of skin panels is readily carried out. Profiles, scalloping, pocketing, end milling, bevel milling operations can all be performed on routers with suitable jigging. Variable bevels can be completed by having a roller at the top and bottom of the cutting tool which bear against templates mounted above and below the workpiece. The workpiece and template system is slung on a jig in trunnions so that it can float axially. Bushes at the top and bottom of the cutter bear on these templates as the work is traversed past the cutter. The different profiles of the templates cause the workpiece to swivel, and thus produce the bevelled form. The jig is carefully balanced so that the axial load is not great. The set up illustrated in Figure 4 shows the technique as designed and used by Morfax Ltd.

2.4 Bevel machining cutter

Figure 5 illustrates another method of producing the bevel on a rib. This is shown as set up on a Hydrotel. The cutter illustrated has three blades with inserted carbide cutting edges, which may change their angular relationship axially. They float in circular ways in the cutter body. A central plunger carries a pinion which engages with a rack at the back of the teeth, and as the plunger is made to move axially, the teeth are made to change the angle which they present to the work. A heavy spring inside the body forms the opposing force to the upwards movement of the central spindle. A vertical face cam mounted on the fixture controls the angle of the bevel. In order to trace the periphery of the wing form, the normal copying equipment of the machine is used and the stylus can be seen to the right of the cutter.

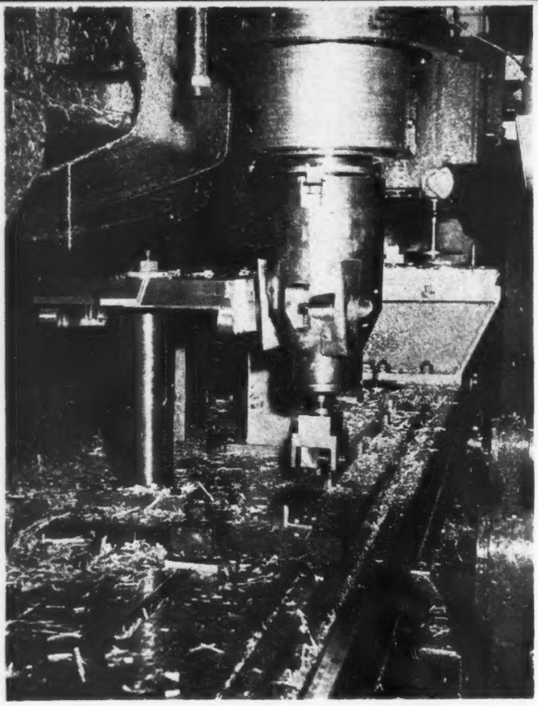


Fig. 5. A variable bevel milling cutter (Vickers-Armstrongs (Aircraft) Ltd.)

2.5 Servo-operated routers

Figure 6 shows a development of the router employing servo operation. A 12 h.p. standard Wadkin router head is used, mounted in a vertical slide. This vertical slide is mounted on a carriage which traverses a beam spanning the machine, thus producing the transverse motion. The beam in turn traverses in the fore and aft direction on two ways at the extremities of the machine. The ways consist of hardened strips and the track is an endless chain which provides smooth running and the minimum of friction. Two vectoring hydraulic jacks are mounted at the back of the machine, and these are linked to a

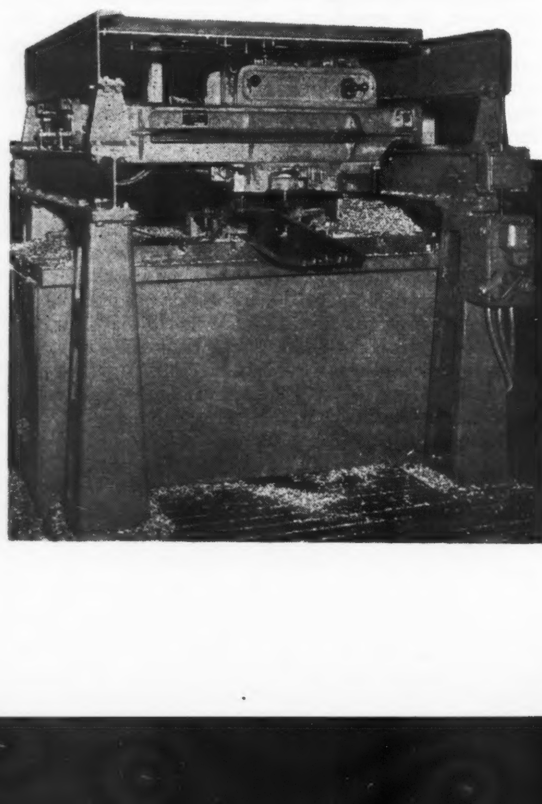


Fig. 6. Servo-operated copy router (Vickers-Armstrongs (Aircraft) Ltd.)

bracket on the traversing carriage. The admission of oil to the jacks causes the head to move in the desired direction. The valving to the hydraulic jacks is mounted just above their point of attachment to the head, and the supply of oil is through the hollow rams. The valves are operated by a vertical stylus. This stylus rod is connected by a linkage to an operator's handle at the front of the machine. Movement of the handle causes movement of the stylus and the opening or closing of the appropriate valves. Thus, as the handle is moved in any direction, the valves cause the jacks to make the carriage move in the direction in which the handle is moved.

Mounted above the table is a template holder. The end of the stylus terminates in a roller the size of which is adjusted according to the diameter of the cutter; roughing or finishing cuts, etc. When the carriage is moved so that the roller engages the template, the stylus is centred and the supply of oil to the jacks is cut off so that the carriage cannot move further in the direction of the template. The attachment of the operator's linkage is spring loaded to the stylus, so that the total stylus roller load is less than 9 oz. The template holder and the work table are drilled with the same pattern of holes used on the overhead template machines to make easy the setting of template and fixture. This machine is extremely fast and accurate, and imposes no effort on the part of the operator.

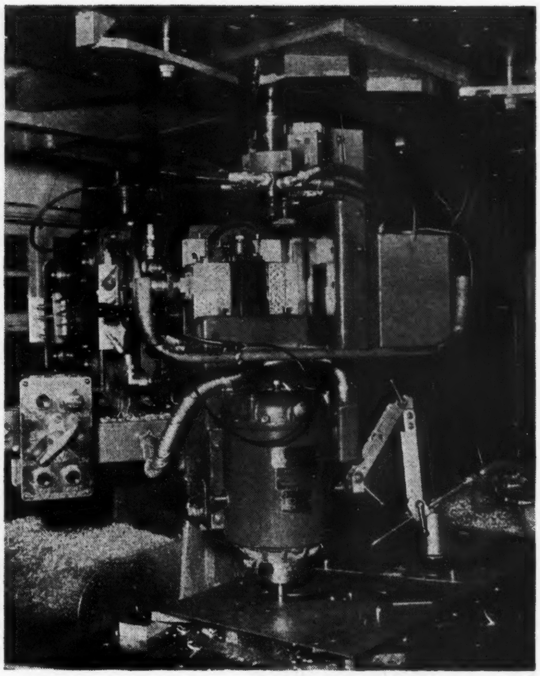


Fig. 7 (above). Vertical hydraulic copy tracer fitted to Wadkin router to provide three-dimensional routing

(Vickers-Armstrongs (Aircraft) Ltd.)

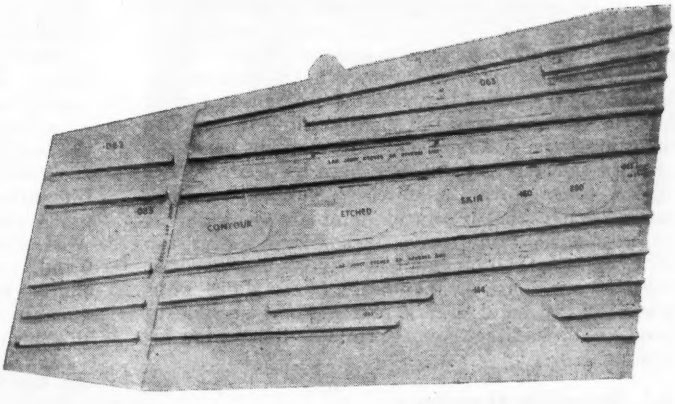


Fig. 8 (right). Contour etched wing skin

(de Havilland Aircraft Co.)

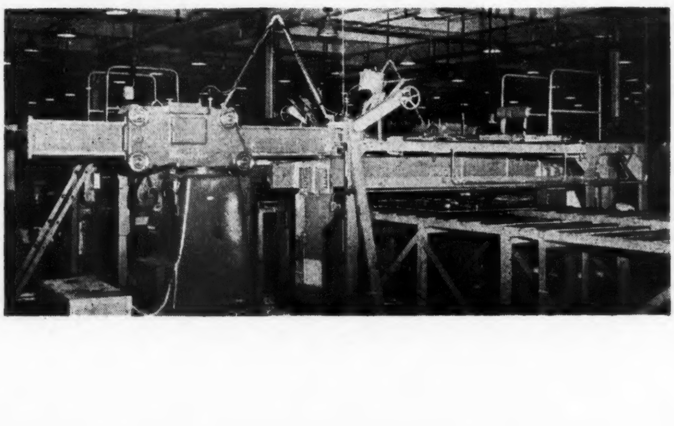


Fig. 9 (below). Skin milling router

(Vickers-Armstrongs (Aircraft) Ltd.)

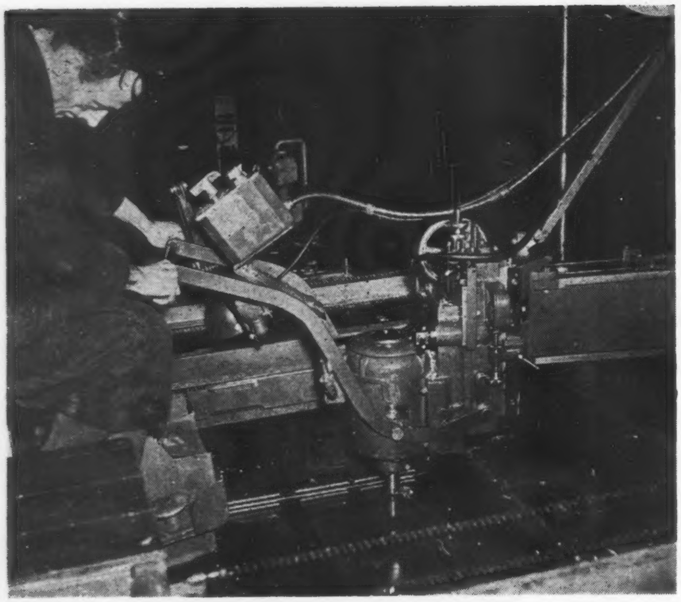


Fig. 10. Operator's position on router skin mill

(Vickers-Armstrongs (Aircraft) Ltd.)

2.6 Three-dimensional routing

A further development is the adaptation of the router technique to three-dimensional copying. Figure 7 illustrates the arrangement. A separate slide is mounted on the end of a radial arm carrying at the overhead template position a hydraulic tracer valve. Another slide carries the router head, and this is balanced. A linkage between the tracer valve slide and the router slide causes them to move in opposite directions; the linkage being operated by means of spring steel strip and thus free from backlash. As the tracer moves over a three-dimensional pattern mounted on the overhead template position, it controls a hydraulic servo jack which moves the slides. The lower router slide describes a movement in the opposite sense to the upper tracer slide. Thus traversing by hand over a pattern, it is possible to produce three-dimensional forms on light alloy by routing.

2.7 Skin milling by routing

Most wing skins and some fuselage skins are now required to be either sculptured or integrally machined. The sculpturing of areas of wing skin can be satisfactorily carried out by chemical contouring but some of the skins are too large for the existing tanks, and also some of the machining is rather complicated. Figure 8 illustrates a large wing skin panel at the de Havilland Aircraft Co. manufactured by chemical etching in six steps from ·280 in. thickness to ·063 in. Lap joints on the reverse side are also etched. Routers have been adapted for this type of machine sculpturing and Figures 9 and 10 illustrate such a machine.

With this machine two radial arm routers span the width of a 6 ft. sheet, being mounted opposite to each other and staggered along the bed of the machine. Underneath the working area of each head is set a table carrying a vacuum chuck. The rest of the bed of the machine consists of a roller conveyor so that the sheets can be moved readily into position in the working area.

The operator sits on a carriage which traverses a bridge over the top of the machine. He is able to control his movement over the work table by means of a foot-operated electrical drive. The templates controlling the cut-outs and the sculptured pockets are bolted directly on to the sheet. Thus they are integral with and move with the sheet as it is traversed along the machine. An area of about 9 sq. ft. is worked on at once, this being the maximum sweep of a radial arm router head. As each area is worked out, the workpiece is indexed to a fresh position on the vacuum table, clamped down and worked upon. By this means the whole of a wing skin is routered.

2.8 Green Linnet machine

The Fairey Aviation Co. Ltd. have done a good deal of work on the development of profile routing. They have designed and manufactured the machine shown in Figure 11, known as the Green Linnet. This employs high speed routing heads of their own design which run at 3,000/6,000 r.p.m. rated at 10/20 h.p. This system employs hydraulic tracer control from a master template. The machine, as will be seen, is of the beam type mounted on a column. Two components can be accommodated at once on the work table, which is mounted vertically. The capacity of the machine is 6 ft. longitudinal by 2 ft. vertical movement. Three types of high-speed milling heads have been designed and produced, the latest of which uses hydraulic dynamic bearings.

In conjunction with Ferranti, Ltd., and the Production Development Department of the Ministry of

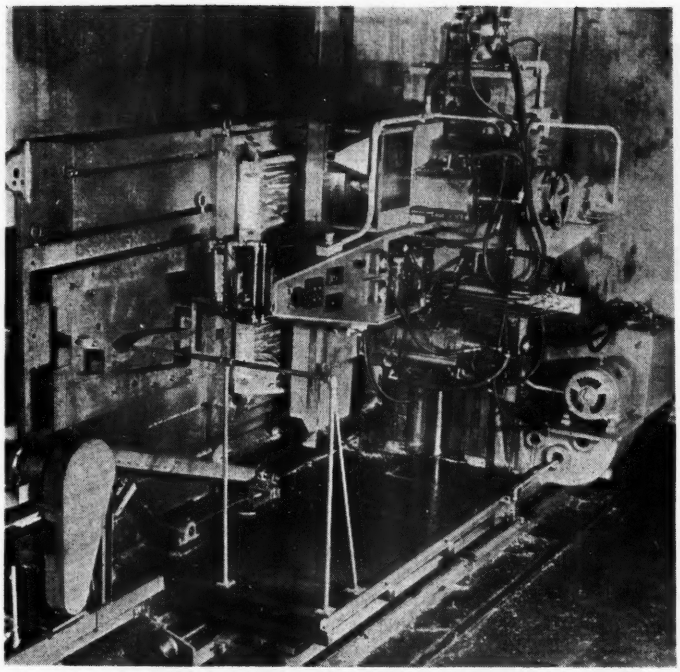


Fig. 11. The 'Green Linnet' copy milling machine

(Fairey Aviation Co. Ltd.)

traverse of 9 in. The table is of heavy construction in cast iron with accurately machined tee slots, and the template is accommodated overhead as shown in the illustration. The stylus tracer is mounted directly over the centre of the cutter.

The main feature of these machines is the use of the Dexter linear ball bearing. It consists of sections of hardened ground rod located in a machined horizontal way. On the traversing member is a similar set of rods, and running between them are standard ball bearings. Side play can be taken up by adjustment to the bearing on the moving member. The balls are continuously circulated. The movement is very smooth in action, and friction is almost entirely eliminated. The bearing will not clog or load up with chips or other foreign matter, as these fall clear

Supply, a large three-dimensional programme controlled milling machine has been built and is now under test at the Fairey Aviation Company. Information is that this machine will be capable of removing up to 50 lb. weight of aluminium per minute under complete control.

2.9 Cramic router

Machines employing the routing principle have been designed by the Cramic Engineering Co. Ltd. Figure 12 illustrates one of these which is employed by the de Havilland Aircraft Co. It is shown routing a wing skin on a vacuum table, the skin being 16 ft. long. The router head has a power of 8 h.p. at 6,000 and 12,000 r.p.m.; 10 h.p. at 9,000 and 18,000 r.p.m., and is mounted on a vertical slide with a

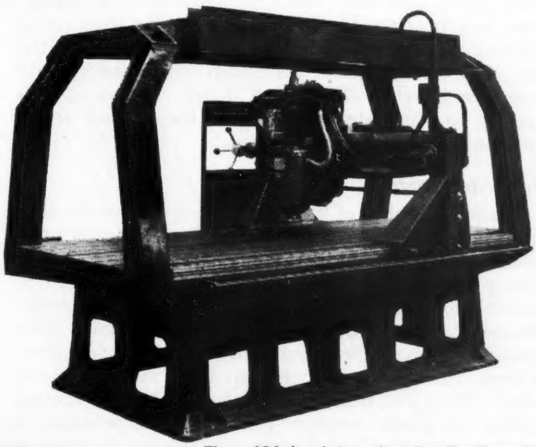


Fig. 12(a) (above). Small Cramic router (working area 6 ft. 4 in. × 2 ft. 4 in.). The Dexter linear bearing assembly is well illustrated in the foreground

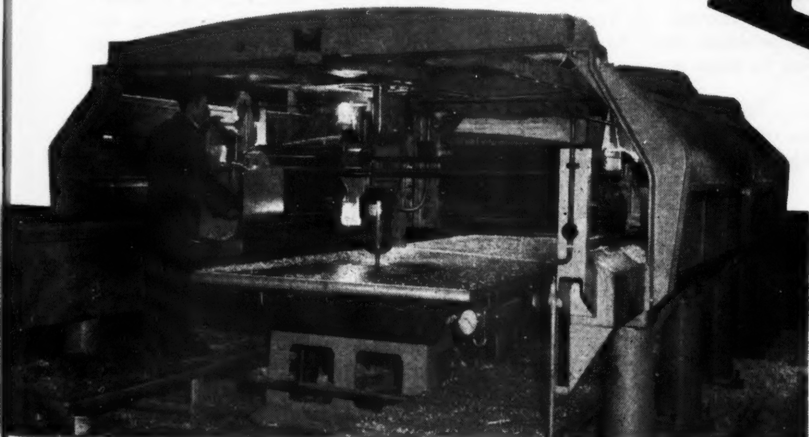


Fig. 12 (left). Cramic overhead template routing machine

(de Havilland Aircraft Co.)

Fig. 13. Cramic routing machine illustrating unit construction
(Cramic Engineering Co. Ltd.)

through the race assembly. The head and tables are driven by two hand wheels at the operator's position, by means of drum and cable motions. A template can very readily be followed and "feel" is quite sensitive.

The Cramic machine is ideal for unit construction as will be seen from the illustration in Figure 13. The working area of this machine is 42 ft. by 6 ft., and is built up in a series of units. There are three work heads, and these can be operated simultaneously. Any length of the Dexter bearing can be built up as desired, its accuracy being dependent only upon the accuracy of the square ways into which the ground rods are inserted. There are many variants of this type of machine dependent upon the various applications for which it is intended.

2.10 Steel routing

Quite a number of firms are attempting to develop the routing of high tensile steels. Router heads have been produced running at 6,000 r.p.m. and of 10 h.p. Using tungsten carbide cutters and CO_2 cooling, it is possible to machine high tensile steels at these speeds. However, cutter life is very short, especially with pocketing, where the pressure on the face of the cutter is high. In the experiments that I am aware of, only about 12-14 cu. in. of material have been removed before the cutter needs re-grinding. The problem is still being tackled but the considerable cutter wear is still the main difficulty.

Ceramic cutters have also been tried, but these break down almost immediately; whether this is from mechanical or thermal shock is not yet known.

3. Milling Wing Skins

3.1 Integral milling of wing skins

Many present British designs call for the use of integrally stiffened wing skins. These are generally comparatively narrow for two reasons, the first of which was the early inability to obtain stretch levelled slab with a greater cross-sectional area than 40 to 44 sq. in. Stretch-levelled slab of approximately 200 sq. in. cross-sectional area can now be obtained, but the wing skins still remain comparatively narrow owing to the application of the "fail safe" design philosophy. Some of these skins are machined upon Onsrud spar milling machines and others have been machined on equipment specially designed.

3.2 Beam type milling machine

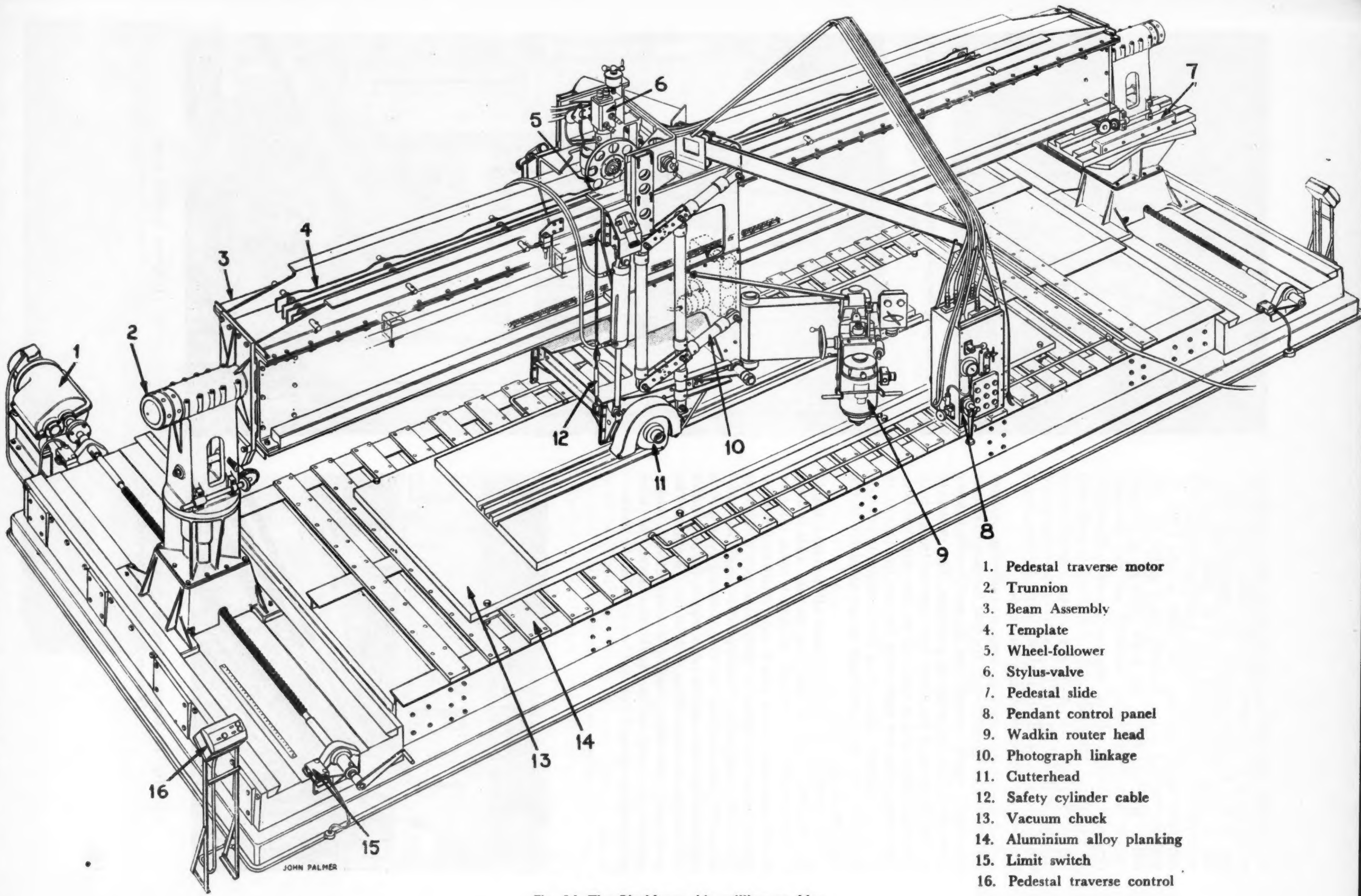
One of these is a tracer controlled beam type milling machine made by Blackburn and General Aircraft Ltd. It is illustrated in Figure 14.

In this machine a fabricated beam, 26 ft. in length, is supported at either end by two travelling vertical members. These members are accommodated in slideways at each end of the machine bed. Since these may be adjusted separately, converging stiffeners, angular stiffeners, etc., can be set up and machined in the components. The beam carries a 50 h.p. Onsrud cutter head, and this is controlled in the vertical direction by means of a hydraulic copying device.

Mounted in the centre of the top of the beam are template holders and a pack of templates can be put in so that various programmes can be completed at one setting. The tracer valve and stylus roller are mounted in a slide assembly bolted on to the top of the cutting head carriage. The Onsrud motor is mounted between link arms which are controlled vertically by means of two hydraulic jacks. As the arms describe a radius, a pantograph system ensures that the stylus roller and the centre of the work spindle are always in vertical alignment so that templates do not have to be specially developed. The work-head can thus be made to rise and fall in order to machine tapered stiffeners and skins, and leave thicker rib platforms where required. A link arm router head is also fitted to the machine to enable cut-outs to be made wherever necessary. Two bladed cutters of up to 17 in. diameter and in face widths of up to 4 in. using inserted tungsten carbide tips, are employed. The surface speed is around 10,000 ft. per minute and at $22\frac{1}{2}$ h.p. 105 cu. in. per minute are removed.

3.3 Machining integrally stiffened wing skins

The arrangement for machining wing planks for the Vickers-Armstrongs Vanguard aircraft is interesting. Figure 15 shows the cutter gang arrangement used on



1. Pedestal traverse motor
2. Trunnion
3. Beam Assembly
4. Template
5. Wheel-follower
6. Stylus-valve
7. Pedestal slide
8. Pendant control panel
9. Wadkin router head
10. Photograph linkage
11. Cutterhead
12. Safety cylinder cable
13. Vacuum chuck
14. Aluminium alloy planking
15. Limit switch
16. Pedestal traverse control

Fig. 14. The Blackburn skin milling machine

an Onsrud spar milling machine for the machining of the integral stiffeners. The light alloy slabs, which are of D.T.D. 5020 material, are supplied in billets 326 in. long, 30 in. wide and 2 in. thick. They are machined in a stretch-levelled, solution-treated, and naturally aged condition. The billet weighs 1,956 lb. and the weight of the finished panel is 151 lb. The billets are held on to the work table on a vacuum chuck, after first being surfaced on the specially designed Cramic milling machine shown in Figure 16. This machine has a table 42 ft. long by 6 ft. wide and the cutter head has a 20 h.p. single speed motor running at 3,000 r.p.m. The horizontal and transverse slides are equipped throughout with Dexter linear bearings of the recirculating ball type.

An Onsrud spar milling machine mills the integral stiffeners. The requirements are that the skin thickness constantly tapers towards the tip and locally thicker areas are left in the wing rib positions. The necessary vertical motions of the cutter head are controlled by a following roller and a cam rail on the machine bed. Very heavy cuts are taken with feeds of from 35 in. to 40 in. per minute. The rate of feed is regulated so that almost the full electrical horse power available in the machine is absorbed.

It is necessary to form the skins after machining to the required profile of the wing section. This is done by shot peening. The locally thickened areas must be formed separately, and this is completed on a special purpose hydraulic press of the type shown in Figures 17 and 18. Designed by Vickers-Armstrongs (Aircraft) Ltd., the press is of the upward stroking type and is adjustable by means of the cams shown, for any radius of curvature down to 20 in. Adjustment is effected by a variable curvature, multiple element die which operates in conjunction with the series of nine independent upward acting 10-ton hydraulic rams.

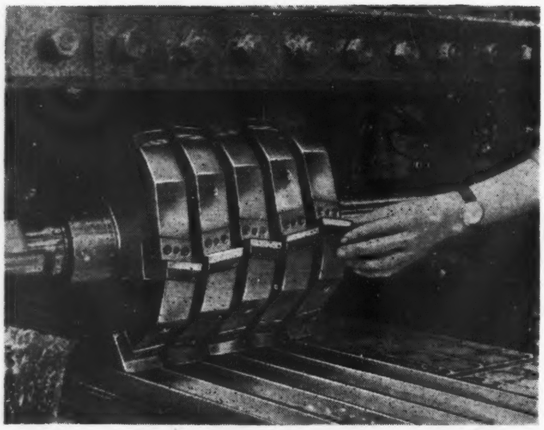


Fig. 15. Cutter gang for milling integrally stiffened wing planks (Vickers-Armstrongs (Aircraft) Ltd.)

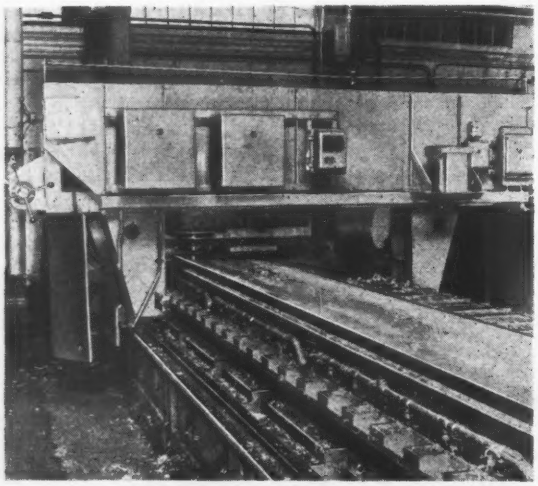


Fig. 16. Cramic milling machine (Vickers-Armstrongs (Aircraft) Ltd.)

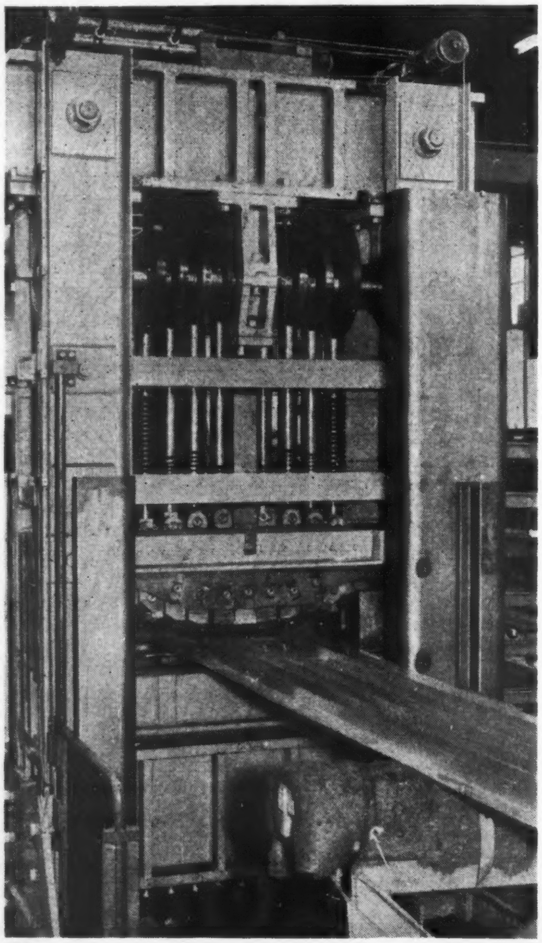


Fig. 17. Special forming press (Vickers-Armstrongs (Aircraft) Ltd.)

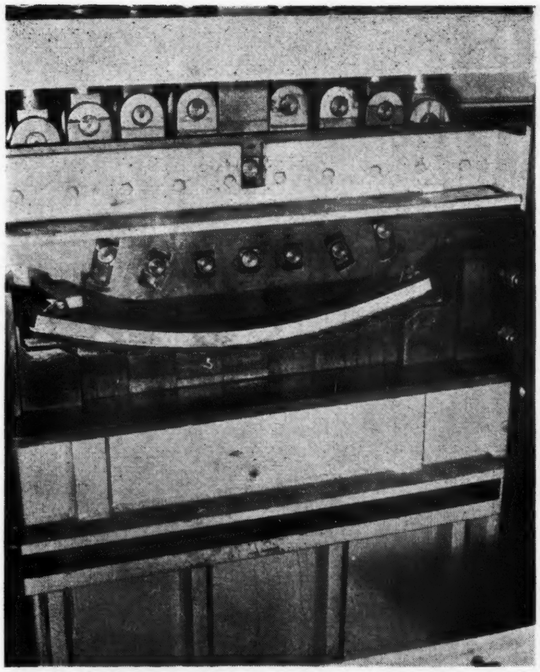


Fig. 18. Close-up of forming head (Vickers-Armstrongs (Aircraft) Ltd.)

In order to minimise residual stresses in the bending operation, this is carried out with the work heated to 200°C., for which purpose electrically heated platens are provided. After the panels have been formed locally, the remaining area of each panel is brought to the required curvature by shot peening the external surface. This treatment has the effect of producing compressive stresses in the surface layers, and is carried out in a plant built by Tilghmans Ltd. to Vickers' special requirements. Spherical steel shot of approximately 0·011 in. diameter is employed and is delivered by a 19 in. diameter impeller.

3.4 Jameson aerofoil generator

The Jameson machine was evolved for the accurate production of large wing panels which obey the laws of straight line generation. It will produce the orthodox type of aerofoil where the generation lines meet at a focal point or a stacking line incorporating offset taper and twist; it will also produce deltas.

The object of the machine is the accurate production of thin aerofoil membranes with the minimum distortion due to thermal stresses set up during machining. The machine has a good metal removal capacity during the roughing operation.

The machine operates by single point cutting in both directions. A very high cutting speed can be employed, as the reciprocating member is of comparatively light weight and the drive, consisting of a screw and an epicyclic gearbox, both have a low moment of inertia. The cutter box reciprocates in a skate slide retractable at its ends hydraulically at the points of reversal. The skate slide is mounted on a member attached to a slide on the face of the centre column. The two end columns act as a further support. The slide assembly is hydraulically locked to the two end columns during the cut.

In the present machine one end column is equipped with a screw connected by a shaft to the main raising screw in the centre column. By altering the ratio between the screws taper can be produced. To avoid high frictional resistance between the raising screw and nut, hydraulic thrusters are used to offload the weight of the assembly. The component is mounted either on compensating jacks or a vacuum chuck attached to the work table, which can be turned to the horizontal position by gears and sectors power operated and mounted in the centre trunnion. Attached to the table are two form plates, one at each end. These form plates correspond in profile to the datum contours of the aerofoil at about 25 ft. centres. The cut is applied by retracting the contour plates by a suitable mechanism which is interconnected by a shaft which spans the length of the table. The ends of

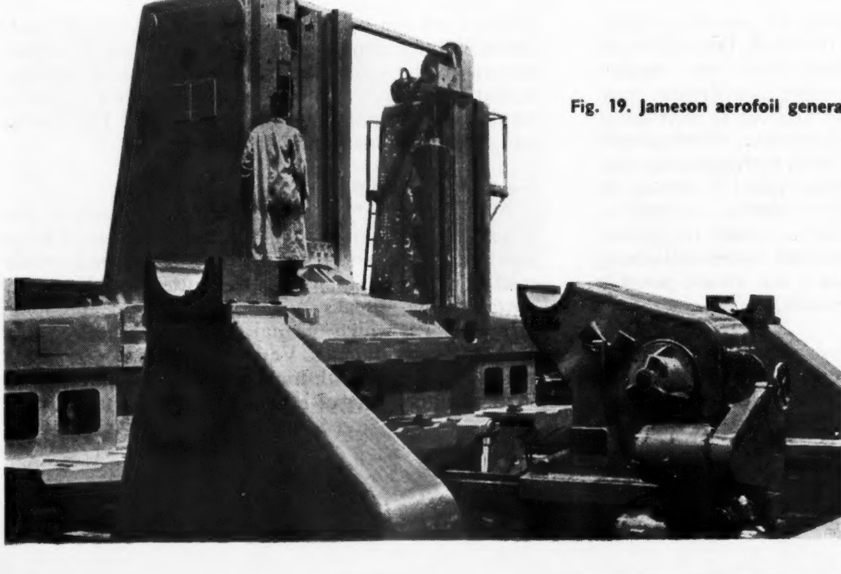


Fig. 19. Jameson aerofoil generating machine during construction (J. L. Jameson Ltd.)

the cutter-box slide are each equipped with a contact member having the same radius as the cutting tool. Figure 19 shows the machine in the course of construction.

4. High tensile steels

4.1 Machining of high tensile steels

Many airframe components are now made from high tensile steels of the order of 80-100 tons. These present a difficult problem in regard to the supply of cutters, cutter life and operational times. Where face milling is concerned, the problem is not so critical because negative rake, inserted tooth face mills can be used and high cutting rates may be achieved. However, the number of machined faces on aircraft components which can be done in this simple manner are very few, and we are mostly concerned with profiling and pocketing, often with long slender cutters which make the problem much more difficult. Generally speaking, these components are machined on hydraulic copy mills such as the Hydrotel and the Rigid mill. Because of the low cutting speeds and tooth loads which can be used, the full h.p. of such machines cannot be utilised. Cutter diameters are small and this too tends to reduce the amount of horse power which can be put into the work. Because it has been found that carbides break down very readily under the elastic drive which exists in hydraulic copy milling machines, we are in the main using high speed cutters. There are, of course, exceptions where people are using cemented carbides. With high speed cutters, however, the maximum surface speed is about 50 s.f.m. and tooth loads vary from ·002 in. to ·008 in. according to the slenderness of the cutter. In general the metal is attacked as much as the cutter will allow, but with slender end mills this is not always possible and the cutter "picks" at the work.

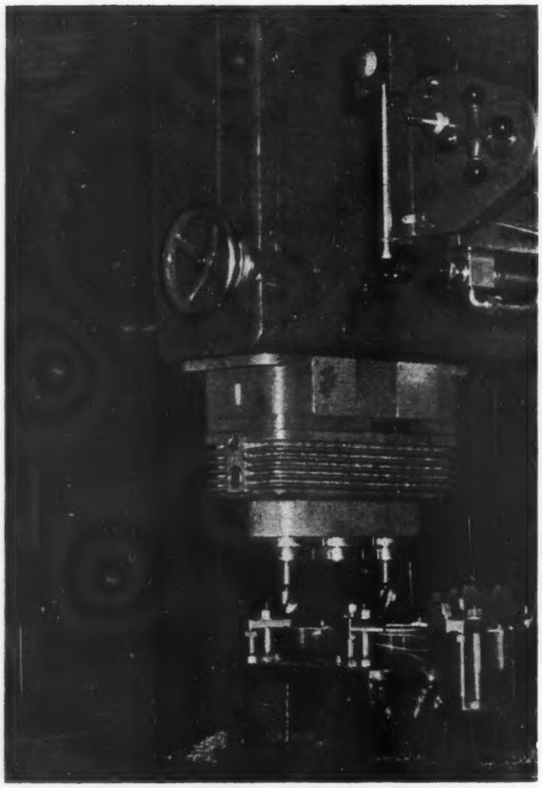


Fig. 20. Twin milling head on Rigid mill (Vickers-Armstrongs (Aircraft) Ltd.)

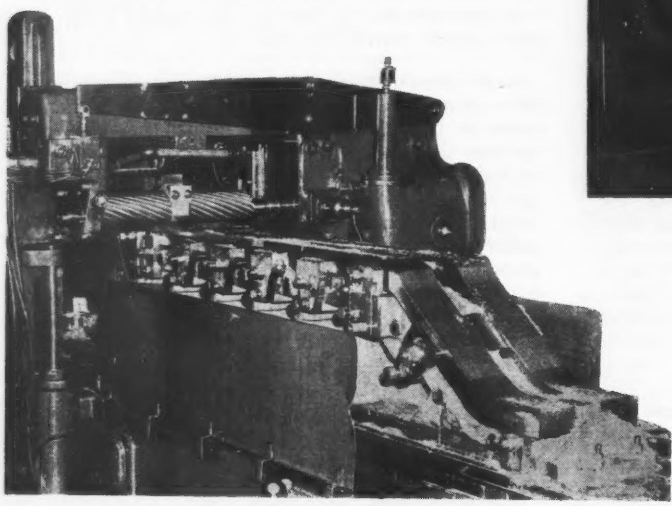


Fig. 21. Strasmann cutters on a Cincinnati Hydromatic milling machine (Vickers-Armstrongs (Aircraft) Ltd.)

4.2 Twin heads

In order to speed up production, a variety of twin heads has been designed and made so that two components can be worked on at once. Luckily, most aircraft components are long in one direction and narrow in the other, so that the problem of accommodating them is a simple one. There are such twin heads available for both Rigid mills and Hydrotels, and these are illustrated in Figure 20.

4.3 Strasmann cutters

A cutter which has been developed recently is the Strasmann type cutter. This has a helical thread form machined on it, and it is made of a high speed cobalt steel. The peculiar form of the cutter lengthens the cutting edge, breaks up the chips from the long acicular form which normal slab mills produce, and reduces the tooth loads. Very heavy cuts can be taken with these cutters with impunity. Figure 21 illustrates such a cutter engaged on the milling of a large spar.

Comparisons of Performance of Milling Cutters on S.99 Spec.—Aircraft Steel.

	Plain Slab Mill	*Strasmann Slab Mill*	*Plain End Mill*	*Strasmann End Mill*	*Inserted Tooth Fly Mill*
Number of Teeth	12	18	6	6	12
R.P.M.	24	24	94	94	40
Diameter	5·5 in.	6 in.	1·5 in.	1·5 in.	5 in.
Feed per minute	0·5 in.	0·5 in.	2 in.	2 in.	1 in.
Depth of Cut	0·1 in.	0·5 in.	0·05 in.	0·1 in.	0·25 in.
Width of Cut	6 in.	12 in.	2 in.	2 in.	5 in.
	Steel Spar Boom—114 in.	Steel Spar Boom—114 in.	Spider Attachment Pockets—40 in.	Spider Attachment Pockets—40 in.	
Life of Tool	½ pass	1 pass	1 pass	4 passes	
Volume Removed per Minute	0·3 cu. in.	3·0 cu. in.	0·2 cu. in.	0·4 cu. in.	1·25 cu. in.
Volume Removed per Regrind	34 cu. in.	684 cu. in.	4 cu. in.	32 cu. in.	60 cu. in.
Volume Removed per Tooth	·00104 cu. in.	·0069 cu. in.	·000345 cu. in.	·000708 cu. in.	·0025 cu. in.
Feed/Tooth/Rev. Max.	·00173 in.	·01116 in.	·00354 in.	·00354 in.	·00208 in.

Fig. 22. Comparisons of performance of milling cutters on aircraft steel
(Vickers-Armstrongs (Aircraft) Ltd.)

On this spar over 600 cu. in. of material are removed. The table in Figure 22 shows the way in which the surface speed and feed can be increased, and the increase in the life of the tool as compared with ordinary high speed milling cutters. The volume of metal removed is increased tremendously, and these cutters are proving very efficient.

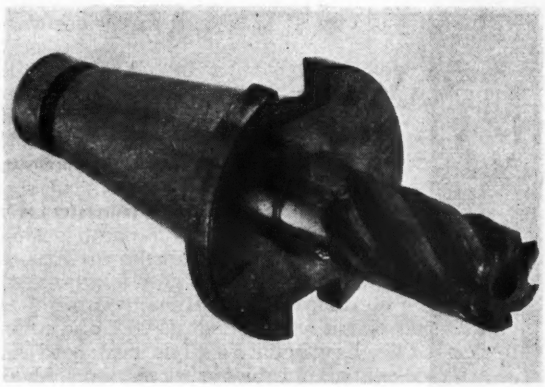


Fig. 23. Six-bladed 1½ in. dia. r.h. helix carbide cutter
(Short Bros. & Harland Ltd.)

4.4 Ceramic cutting tools

Most firms have been carrying out experiments with ceramic cutting tools. They have proved to be reasonably efficient in the single point turning of Nimonics. In my experience, they are not yet so satisfactory as cemented carbides for other materials. No success has yet been achieved with milling cutters having ceramic tipped teeth. They do not take kindly to shock loads, and thermal shock will also break them down very quickly.

4.5 Spiral carbide cutters

Spiral carbide cutters have been developed by Production Tool Alloys, of Sharpenhoe, and these are available to the industry. Aircraft Production Development initiated their manufacture and Short Bros. & Harland did the production testing and development. They have been used by Short Bros. & Harland for the machining of flap tracks, etc. The finish is extremely good and there seems to be a future for this type of cutter upon further development (Figure 23).

4.6 Gun reaming

The same firm has adapted the gun reamer for the production of reamed holes with a very high finish in high tensile steels. This gun reaming technique has

been described elsewhere, and its great advantage is that high speeds are obtained, together with finishes of the order of 6 micro in., and the reamer acts as a single point tool cutting its own path through the material. Thus it will not "run" and follow the path of the previously drilled undersize hole (Figure 24)

5. Programmed control of machine tools

5.1 Numerical control

Many aircraft firms are considering numerical control for machine tools. Some have machines fitted with this type of control which are already working, and some are producing machines for themselves together with the associated controls. There are a number of systems available—among them Ferranti Ltd., E.M.I. Electronics Ltd., Ekco Electronics Ltd. and British Thomson-Houston Co. Ltd. These systems have been applied to standard milling machines, but in the future we must consider the design of the actual machine tool in conjunction with the electronics.

5.2 Co-ordinate positioning

Figure 25 shows a co-ordinate drilling machine operated by means of punched paper tape. In this machine a count is taken straight off the lead screw which is of the recirculating ball nut type made to an accuracy of $\pm$·0003 in. per foot run with an overall accuracy of ·002 in. Jig boring accuracy is not considered a requirement for the purpose for which the machine is intended, which is to drill large aircraft fittings without drill jigs. It is considered that if an overall accuracy of ·001 in. between a group of holes is attained, this will be sufficient for normal aircraft practice, and so long as the spacing of one group of holes to another is within ·003 in., this will meet the general requirements of the drilling of large aircraft components. The machine has been specially designed to match the electronic gear and the table is mounted on roller slideways to reduce inertia and friction. Both machine and electronic control have

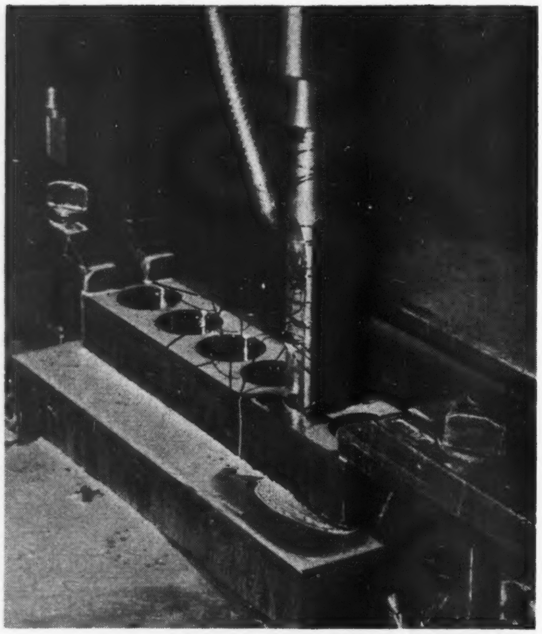


Fig. 24. Reaming holes 1¼ in. in dia. in S65 (55 ton steel) at 600 r.p.m. and a feed of 0.008 in./rev.
(Short Bros. & Harland Ltd.)

been designed by Vickers-Armstrongs (Aircraft) Ltd.

Mounted on the end of each lead screw is a geared slotted disc. This disc interrupts light from a light source and a pair of photo-electric cells mounted behind the disc count the resulting pulses of light. The arrangement gives one pulse for every ·001 in. increment of movement of the slideway. Punched paper tape coded with the co-ordinate positions is fed through a normal teleprinter reading head, the

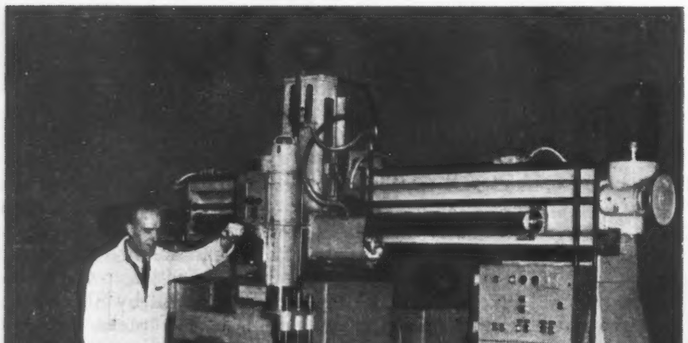


Fig. 25. Numerically-controlled co-ordinate positioning drilling machine
(Vickers-Armstrongs (Aircraft) Ltd.)

Fig. 26. 'Atlantic' numerically controlled co-ordinate positioning drilling machine (Industrial Technics Ltd.)

connections of which are made to banks of uni-selector switches. The switches move to a position which is an analogue of the ordinate number punched into the paper tape. Each switch position is connected to the corresponding cathode position of a bank of decatron valves arranged in cascade, so that the number put into the uni-selector is transferred to the decatron counter. When the table moves, the pulses from the interrupted light source are counted by the decatron valves so that when the table has moved the requisite number of thousandths of an inch, the count on the decatron valves is reduced to zero and the motion stops.

Arrangements are made so that the table movement is progressively slowed down as the unit thousandths are approached, thus the final position is reached slowly in order to eliminate inertial over-run. A self-inspection system is built into the controls by punching a second tape with the complement of the original ordinate. This second tape controls a second bank of decatron valves so that whilst one series counts to zero, the other counts to 99·999. It is unlikely that the electronics will miss a pulse in both counting units at the same time. If the two counts do not therefore add up to 99·999, the machine signals that an error has been made and the drilling head will not operate. Inching buttons are provided so that the operator can correct the miscount and the machine will then operate.

5.3 E.M.I. co-ordinate positioning

There are quite a number of other co-ordinate positioning machines. Among them is the machine illustrated in Figure 26. This machine is made by Industrial Technics Ltd., of Southampton, and employs E.M.I. co-ordinate positioning controls. The slides incorporate linear type re-circulating ball bearings which run on hardened and ground bar suitably mounted on the bed. The Farrand Inductosyn is employed as the measuring system, and this can signal back to the electronic control, table positions to an accuracy of ·0002 in. The machine has a table size of 36 in. by 30 in. The stroke of the spindle quill and its return can be pre-set and automatically cycled from the electronic control. Information is put into the console by means of punched paper tape.

5.4 B.T.H. co-ordinate positioning

The British Thomson-Houston Co. produce an extremely accurate co-ordinate positioning system which can be and is being fitted to jig borers. This has a repeatability of position of ·0001 in., and the information is fed into the console by means of punched cards. The control system employs electro-magnetic methods. The measuring bar is of magnetic material having a series of holes bored at one inch centres which are filled with non-magnetic inserts. This is mounted on one part of the moving system, and a detector head comprising a differential transformer, is mounted on the other. The electrical balance is measured by the control and the detector head is positioned by synchros to the decimal portion of the ordinate to be set. The leadscrew is then moved by the controls until the detector head is symmetrically disposed with respect to the nearest hole. Figure 27 shows the control fitted to a Newall Spacematic jig borer.

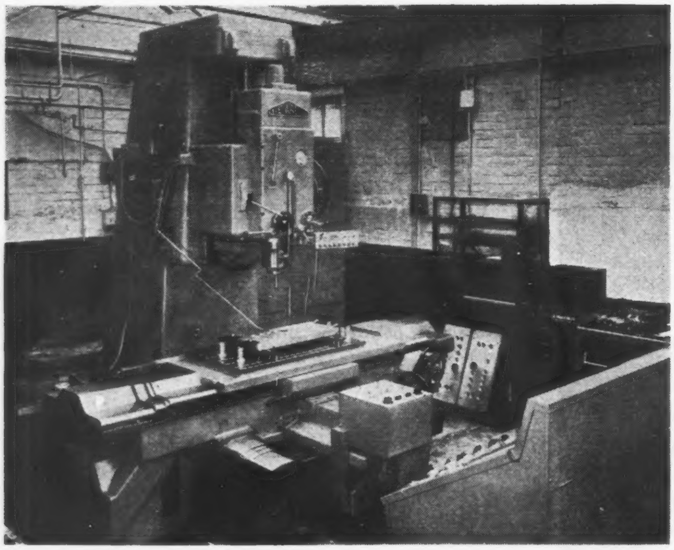


Fig. 27. B.T.H. co-ordinate control fitted to a Newall Spacematic jig borer

(B.T.H. Co. Ltd.)

5.5 Ekco co-ordinate positioning

A very neat and simple automatic co-ordinate setting control is manufactured by Ekco Electronics Ltd. It can be set up on almost any two-dimensional system such as a milling machine or the like. Its compact appearance is illustrated in Figure 28. The control is fitted directly on to the lead screw of the machine, and accuracy is, of course, dependent upon the accuracy of the lead screw, although if the inaccuracies are known and plotted, these can be allowed for in setting up the ordinates. It will set any lead screw to within 1/500th of a single turn, and on a 10 t.p.i. screw this means to ·0002 in. linear movement of the work table. On a 4 t.p.i. lead screw the accuracy of re-setting would be around ·0005 in. The system is an analogue one consisting of a series of Wheatstone bridges, the master potentiometers of which are set up to the desired measurement. The ordinates are "rung" in by hand on a control box to four decimal places, these controlling the potentiometers. The drive motor to the lead screw is of ¾ h.p. Development work is in hand for a punched card information storage system.

5.6 Simple co-ordinate positioning

A very simple co-ordinate positioning device is being developed by Vickers-Armstrongs (Aircraft) Ltd., and basically this consists of a series of commutators geared to the lead screw of a co-ordinate table. If there are 10 segments on each commutator and these are geared in decade form so that the ultimate commutator is capable of discriminating ·001 in. travel of the table from one segment to another, then at any position of the table a unique electrical pattern will be described in series through the commutators via the different segments. The console control consists of simple rotary switches set up in decade form by means of which are set a series of magnetic relays, so that these are an analogue of the desired path through the commutator system. Electrical controls bring the two into balance. It will be seen that with the minimum of relays and commutator positions, the table may be set to increments of ·001 in. Like the Ekco device, this employs no valves in the control. The device is under development at the moment.

5.7 E.M.I. numerical control

There are several continuous two-dimensional numerical control systems. The machine tool control made by E.M.I. Electronics employs an analogue system, and can be fitted to quite a number of standard machine tools. It has been fitted to Cincinnati and other type vertical milling machines.

Fig. 28. Ekco co-ordinate positioning control box as fitted to one leadscrew element

(Ecko Electronics Ltd.)

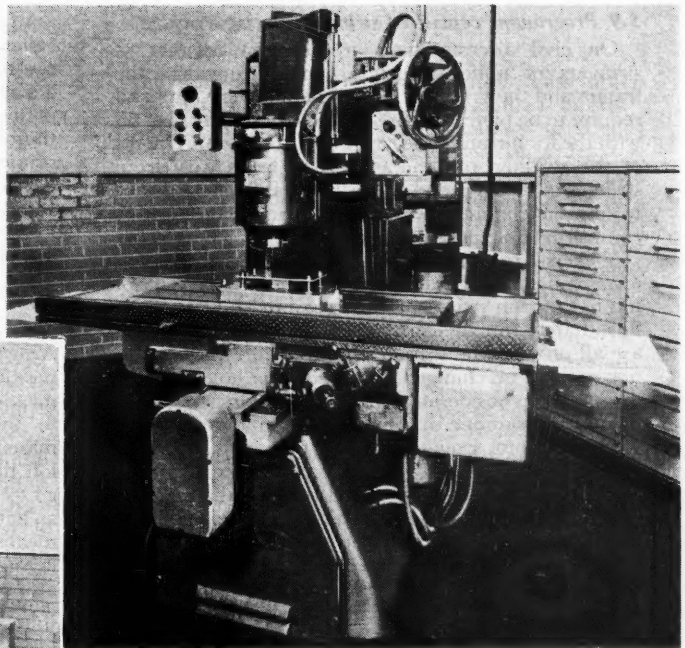


Fig. 29 (right). Wadkin high speed vertical mill, fitted with E.M.I. continuous two-dimensional numerical control
(Wadkin Ltd.)

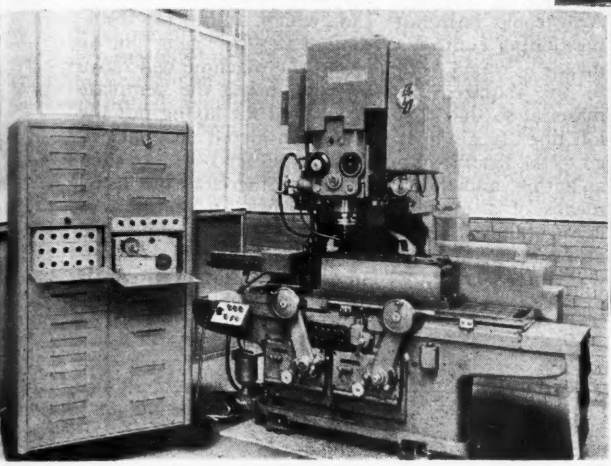


Fig. 30 (below). E.M.I. electronic machine tool control (three-dimensional programme control) fitted to a Hydrotel
(E.M.I. Electronics Ltd.)

Figure 29 shows a Wadkin high speed vertical milling machine fitted with this device. The system employs analogue voltages to interpret the numerical position of the machine tool table. The table positioning is read directly off the lead screw, and a gear box and potentiometer series system is geared to the lead screw. In the control itself, voltages are tapped off toroidal transformers by means of relays, which are operated by information taken from punched tape passing through the reading head. The voltages are matched with the voltages from the potentiometer, and thus control the machine tool position. Continuous interpolation is provided between every three points specified on the programme, ensuring accurate profiling and good surface finish. The punched tape passes through a reader, which records the information in a relay store where it is retained until it is required when the next piece of instruction is fed through from the tape. The speed of the tape is controlled by the cutting speed of the milling machine, so that the information being worked upon at any time always refers to the place where the machine is cutting. Adjustments for cutter size and cutter wear are provided.

The control can also be fitted to hydraulic copying machines where the table is operated by hydraulic motors or rams. Hydraulics have a greater rate of acceleration than electric motors and therefore the speed of profiling is greater. Figure 30 shows this control fitted to the three axes of a Hydrotel, thus giving three-dimensional machining.

5.8 Ferranti numerical control

Ferranti Ltd. market a digital data control system for automatic continuous three-dimensional control of machine tools. Figure 31 shows a Kearney and Trecker milling machine fitted with this device. The positions of the machine tool elements are monitored to an accuracy of ·0002 in. by means of signals from a diffraction grating system. In this, optical gratings are used which are ruled with lines 2,500 to the inch. One such grating is fitted along the bed of the machine and another short length is fitted to the carriage so that as the table moves, these are passed over one another. There is a slight angular displacement between the two so that as they move, bands of light and dark pass over the axis of the grating when a light source is placed behind, and these are counted by photo-electric cells. Directional control of table movement is achieved because the photo-cell system can discriminate between the light bands moving upwards or downwards.

Electronic control is by means of magnetic tape. A programme giving the changepoints of the path which it is desired that the cutter should follow, is fed into a computer and this works out the continuous path which must be traced out under the cutter head. This is translated into pulses on the magnetic tape, which can be balanced against the feed back from the machine tool table through an electronic system driving a servo motor. The electronic control system is highly sophisticated and can be adapted to almost any machine tool.

5.9 Programme controlled stringer piercing machine

On civil aircraft there are a large number of stringers of uniform section, linking together the frames and the skin. They are generally very long and require to be pierced or pre-drilled where they pick up with the frames and other members. The requirements of the drilling and the groups of holes vary from stringer to stringer, and hitherto, it has been necessary to use machines carrying metal templates which control the hole positions.

Vickers-Armstrongs (Aircraft) Ltd. have designed a machine which automatically pierces any type of top hat section stringer to any required hole pattern. Fortunately, on the aircraft concerned the stringers are all of the same section, and therefore the dies do not need to be changed. However, the hole requirements vary considerably. The only tooling required to change from one drilling programme to another is the provision of a punched paper tape.

This is fed into a reading head and under electronic control the stringer is advanced through the piercing head where four pneumatically operated punches pierce the holes in the correct positions. The stringer is advanced through the piercing head by means of a rack and pinion drive and the count is taken directly off this. The electronic system is basically the same as that described for the co-ordinate drilling machine, using the interrupted light source and a decatron valve circuit for counting. The pneumatic circuit is controlled by means of electro-pneumatic solenoid devices from instructions on the tape. As each punching position is reached, the stringer is held stationary by means of an electric brake. The appropriate pneumatic circuit operates the punch to pierce the hole or holes, and the stringer is again advanced. Information has therefore to be punched into the tape to control the pneumatics in addition to the positioning of the stringer.

5.10 Template lofting machine

A lofting machine has been made for Vickers-Armstrongs (Aircraft) Ltd. which utilises electronic positioning control. Ordinates can be "rung" in by means of rotary switches and the machine will move to the required position and mark the template material so that this can be used for laying out the loft lines. It is not at present considered necessary to go to the trouble of punching tapes for 1-off jobs such as lofting, and the information is therefore put in by means of a manual switch board. In addition to laying out the template material, the machine will also rule any desired grid system on the template and will interpolate any curve. An optical system is provided for interpolation, which by bringing a pair

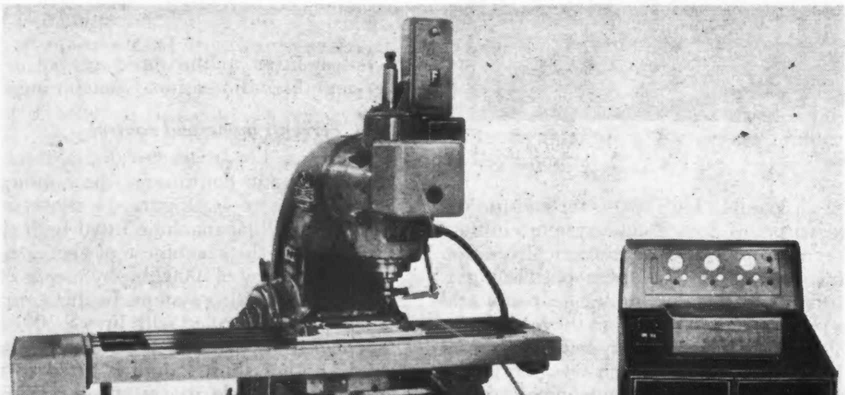


Fig. 31. A Kearney & Trecker milling machine fitted with the Ferranti three-dimensional numerical control

(Ferranti Ltd.)

of cross lines on the curve and reading off the ordinates on a bank of decatron valves, enables any empirically obtained curve to be measured and recorded accurately.

Ferranti Ltd. have also produced a similar type of machine. This is based on their well-known two-dimensional continuous positioning control and draws out the actual profile of the component on stable material. Other manufacturers are designing and offering similar machines.

5.11 Advantages of numerical control

Continuous experimentation and development is proceeding in the U.K. at the present time on the development of numerical control. In the aircraft industry this offers the means by which the lead time on aircraft can be considerably reduced. Numerically controlled machines need very little in the way of complicated tooling. A fixture which will hold the component being worked upon in correct position with relation to a fixed datum and a punched paper tape or magnetic tape is all the tooling that is required. Modifications are easily incorporated; for example, with drilling, the basic holding fixture need not be altered, and any new holes or hole positions can be readily accommodated by changing the information on the tape—a very simple matter. This is not automation, for the greatest advantage of this type of machine tool control is that it is eminently suitable to small batch production with the minimum of tooling.

6. Manufacture of aircraft pipes

6.1 Pipe bending

The numbers of pipes required for aircraft assembly have increased enormously, and the load on the coppersmiths, sections makes it necessary to adopt mechanical means of pipe bending. In order to manufacture by mechanical means, it is necessary that every bend in a pipe shall be to a true radius and to standard bend radii for which there are bend blocks available. The prototype run of pipes is controlled to this requirement by standard instructions to shops and inspection. If these instructions are followed, then it is possible to machine bend almost every pipe in an aircraft run. There are, of course, positions in the aircraft and pipe requirements which make it necessary to use non-standard runs, but these are small in number and can be dealt with by normal coppersmithing methods.

There are many different types of standard pipe benders being used in the aircraft industry. Among them are the Pines, the Parker, the Hilger and special pipe bending machines developed by aircraft firms for themselves.

6.2 Bending small diameter pipes

Other developments on machine bending have been made. Figure 32 illustrates a small pipe bending machine for the manufacture of pipes up to $\frac{7}{16}$ in. diameter. On this machine, a floating travelling carriage moves along the bed. On the carriage is mounted a chuck into which the pipe is locked. This chuck can be rotated in order to provide for bends in different planes. At the back of the chuck is a dial marked off in degrees to facilitate setting. A series of adjustable stops is mounted on a capstan spindle carrying the chuck. Fixed to the body of the carriage is a series of latches which can be brought into action, one by one, to limit the movement of the capstan stops, which can be set to the various angles required by the pipe run. The latches are brought down in sequence as each bend is produced; the stops controlling the radial setting of the tube.

Mounted along the bed of the machine is a bar, and on this bar slide a number of stops which can be adjusted to given lateral positions according to the distance between the bends on the pipe. These stops are set numerically in conjunction with a ruled index set on the bed of the machine. At the bending head, a spindle carries an operating lever on the underside and on the top a dogged spindle upon which the various bend blocks are mounted. This spindle is connected by chain to a vertical capstan and stop assembly similar to the one described on the moving carriage. These stops can in turn be set so that they limit the radius through which the pipe can be bent.

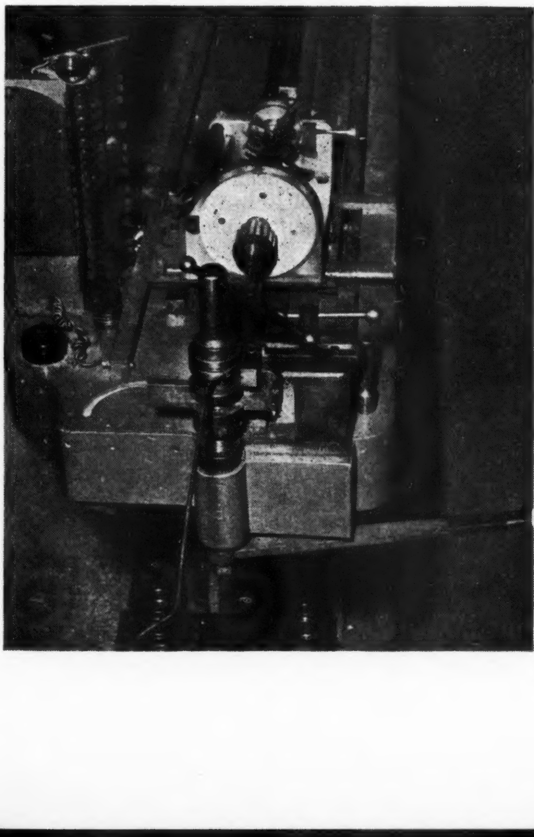
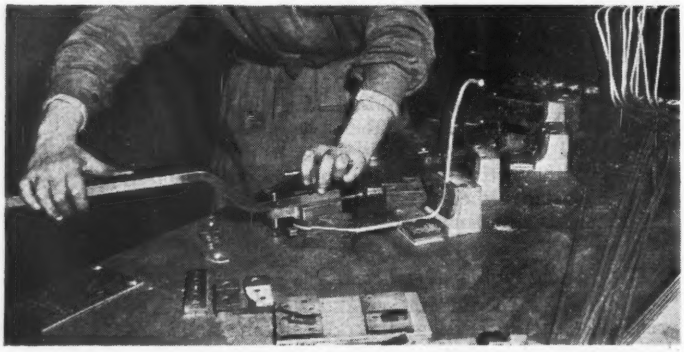


Fig. 32. Capstan-controlled, sequentially operated pipe bender for small diameters

(Vickers-Armstrongs (Aircraft) Ltd.)

Fig. 33. Jig board method of controlled pipe bending
(Vickers-Armstrongs (Aircraft) Ltd.)



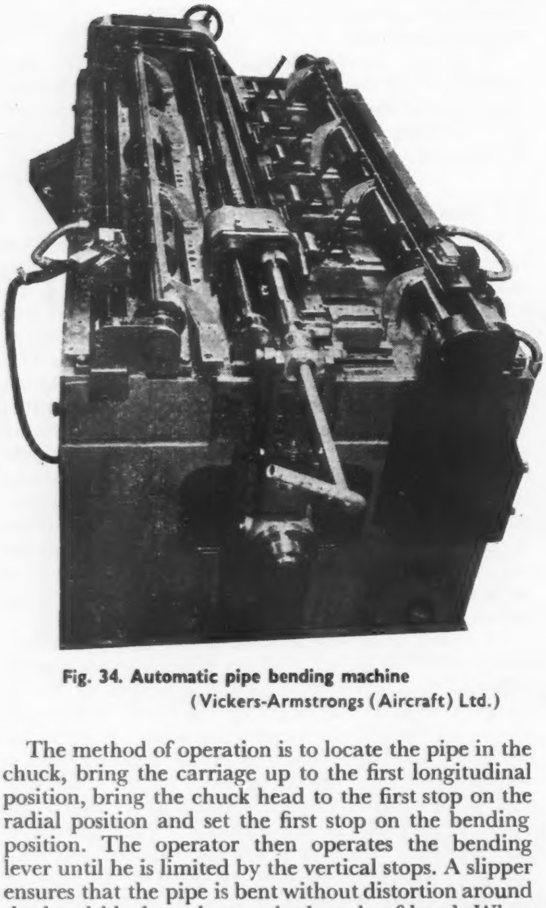


Fig. 34. Automatic pipe bending machine
(Vickers-Armstrongs (Aircraft) Ltd.)

The method of operation is to locate the pipe in the chuck, bring the carriage up to the first longitudinal position, bring the chuck head to the first stop on the radial position and set the first stop on the bending position. The operator then operates the bending lever until he is limited by the vertical stops. A slipper ensures that the pipe is bent without distortion around the bend block to the required angle of bend. When that is completed, the carriage is pulled forward to the next stop. The pipe is rotated to the next stop covering the angle of bend, and the next vertical stop is brought into position controlling the amount of bend, and so the next bend is made. Thus by advancing the carriage along the series of stops on the bed and bringing in the angular stops in turn, it is possible to produce any pipe from $\frac{1}{8}$ in. to $\frac{7}{16}$ in. diameter by hand. The pipes so produced are very accurately formed and fit the jig boards easily Normal pipes can be produced at the rate of about one per minute.

When a new pipe is received, it is analysed numerically and the figures are translated into machine settings. Some slight adjustment may have to be made due to spring-back, etc., but as soon as these adjustments have produced a perfect pipe the stop positions are recorded and thereafter this analysis of the pipe is used to set the machine.

6.3 Mechanical bending on jig boards

Figure 33 shows a similar method employing wooden jig boards. On this the operator applies a bend block and lever to a jig board in specified positions in ordered sequence. The bending lever operates a slipper which pulls the pipe around the block. The edge of a plate set on the jig board indicates the amount of the bend, and this is sighted by eye by the operator. As the pipe is set by eye, spring-back allowance is automatically made. When one bend has been produced, this bend is used for location for the next bend. The jig boards are made so that the pipe is produced by a series of bending positions, each one of which locates by the bend which has previously been made. Upwards of 10 to 20 pipes per hour can be produced according to complication.

6.4 Extrusion bending of pipes

A machine is under development which will extrude a pipe through a die to the required form. This machine is illustrated in Figure 34. The pipe is located in a collet mounted on a carriage which moves along the bed of the machine, the carriage being driven by a 3 h.p. motor through a lead screw. The pipe first moves through a fixed die and then through a movable die. If this die is displaced in relation to the other as the pipe is extruded, the pipe will emerge in the shape of a bend—the greater the displacement the tighter will be the bend.

Control of the amount of bend is brought about by means of a countershaft containing a series of cams which can be set to any desired position by numerical means. This countershaft is linked with the die move-

Fig. 35. Pipe flaring machine
(Vickers-Armstrongs (Aircraft) Ltd.)

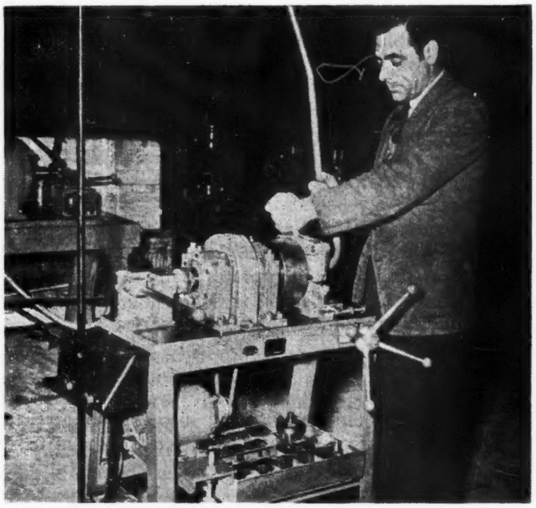


Fig. 36. Pipe bending machine
(Vickers-Armstrongs (Aircraft) Ltd.)

ment and both are driven by a $\frac{3}{4}$ h.p. motor. As the main carriage advances along the lead screw, a second carriage carrying a probe and micro-switch moves along the countershaft. When the probe engages one of the rotary cams, the micro switch is closed, the motor operates, and die movement takes place. The cams have slots cut in them so that according to their setting, when the cam has rotated by the desired amount, the probe drops into the slot and switches off the current to the motor operating the moving die. Progressive contact with cams mounted along the countershaft moves the die up and down to produce the pipe bends in sequence.

A second countershaft and carriage system similar to the first rotates the collet into which the pipe is mounted, in order to control the proper angular relationship between each bend. The cams on this can also be set so as to rotate the pipe by the required amount. Thus the pipe is extruded into the shape required. This machine is under continuous development at the present time. There are still a few snags to be overcome in the way of repeatability. Slight differences in the diameter and hardness of the pipe bring about slight discrepancies in the pipe, but these can be adjusted quite easily by hand.

6.5 Pipe bending by numerical control

It is intended to eliminate the setting by cams and substitute instead electronic control by means of punched tape. It will readily be seen that since the pipe can be described numerically, application of a count system and control by tape can control the movements of the die and the rotation of the collet. This will eliminate the necessity for setting up the machine, as the only tool required for producing a pipe will be a piece of punched paper tape, and the only setting up needed will be the insertion of the appropriate diameter dies and holding collets.

A great deal of attention has been paid to the manufacture of pipes in order to reduce the time necessary for their production, and this work will go on progressively.

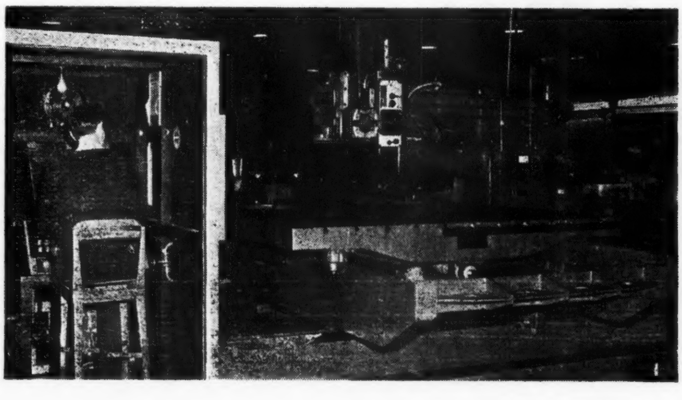


Fig. 37. Template making machine.
(Vickers-Armstrongs (Aircraft) Ltd.)

6.6 Pipe flaring and beading

Only a few years ago, we were flaring pipes by hand and beading them by means of bench jennies. Figure 35 shows a pipe flaring machine which operates by rolling an eccentric punch into the pipe and flowing it into a fixed die. Figure 36 shows a machine which has been developed for the beading of pipes. This operates by the controlled eccentricity of a roller which rolls the bead into a pair of dies. The eccentric roller is returned to the central position for the loading of the pipe and progressively brought out to the eccentric position required to roll the bead into the die by means of a brake applied at the back of the machine. This operates through a differential shaft and cross head to produce the movement of the roller.

7. Template manufacture

7.1 Template-making machine

Routing and copy milling techniques require a considerable number of profile templates, both large and small. To cut and file these by hand in the toolroom is a costly matter. In general the profiles of these templates are determined by lofted methods, either by lithographic or photographic means. That is to say, in most cases, there is no necessity to lay the templates out from ordinates, but these can be transferred directly from a loft plate.

In order to be able to produce templates quickly and cheaply, a template making machine has been developed, as shown in Figure 37. The table of the machine is 8 ft. by 8 ft., thus being able to accommodate 8 ft. by 4 ft. standard loft plates and 8 ft. by 4 ft. templates. Longer templates can be handled by indexing the loft plate and the template along the table. The table is mounted on a double slideway system on 1 in. diameter roller chains to reduce the friction to the minimum. The transverse and longitudinal traverses are operated by means of two hydraulic jacks. The power to the hydraulic jacks is fed through a four-way vertical hydraulic valve system. To operate these valves, a steering wheel controlling the movement of a swash plate depresses the valves in turn in order to steer the table in any direction. The swash plate is connected to an accelerator pedal so that the greater the deflection of the plate the more oil is admitted through the valves, and the faster the traversing speed.

The loft plate is mounted on one half of the table underneath an optical system. This optical system passes the image of the loft plate through a lens system and a series of mirrors to be projected on a screen 20 in. by 20 in. which is contained in an operator's cabin. The template to be cut is mounted on the other half of the table over which is mounted a cutting head, which can be varied in speed from 187 to 6,000 r.p.m. with 5 h.p. on the spindle. The head is thus able to mill light alloy or steel, or carry out drilling operations.

The magnification of the image is 10X. Therefore a disc ten times the diameter of the cutter employed is mounted on the centre of the screen. The operator sits in the cabin and steers the table so that the image of the line on the loft is presented tangentially to the periphery of the disc mounted on the screen, rather like steering a motor car down a winding road. The path traced out by the table as it is made to follow the line drawn on the template, is reproduced by the cutter on the template material, and thus the template is produced.

Adjustments in the diameter of the control disc can make allowances for flanges, adjustments for gauge thicknesses, and so on. Templates made in this manner need only slight draw filing and dressing of the edges to remove burrs and slight cutter marks.

8. Use of titanium

8.1 Titanium

Titanium is being introduced into British aircraft design at an increasing rate. So far it has been used

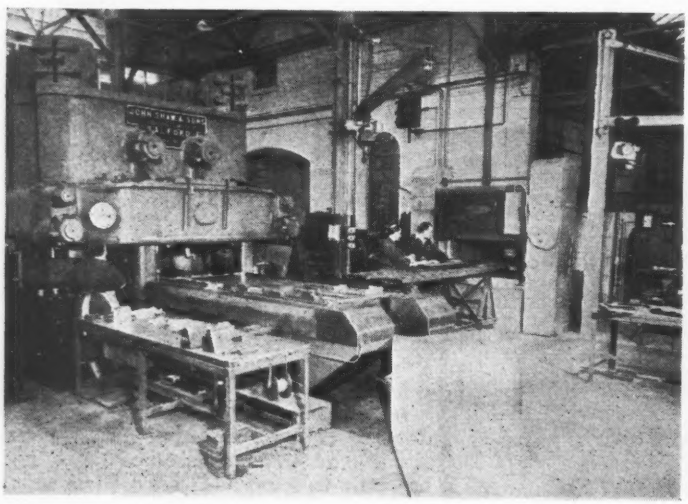


Fig. 38. Hot forming of titanium parts; rubber press arrangement
(English Electric Co. Ltd.)

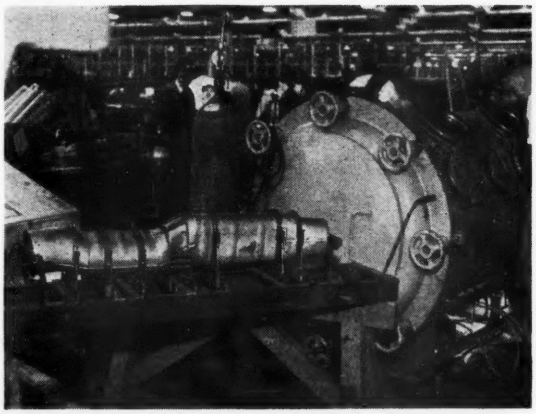


Fig. 39. Argon chamber for welding titanium (de Havilland Aircraft Co.)

mainly to replace stainless steel where heat-resistant and corrosion-resistant properties are necessary. This includes such items as engine bay and jet pipe aperture linings, gun blast tubes, ammunition boxes, louvres, jet exit fairings, hydraulic header tanks, flame proof bulkheads, hot air pipes, etc. Considerable quantities of titanium are therefore being worked upon in forming, cutting, welding, etc. No difficulty has been found in forming commercially pure titanium.

8.2 Hot forming titanium

The English Electric Co. are carrying out hot forming of alloyed titanium. This is being completed on a rubber die press using a silicone rubber insulating blanket to protect the rubber bolster in the press. Titanium parts and form blocks are heated to around 300° C. in an electric oven adjacent to the press table. The form blocks are made in steel. Figure 38 shows the arrangement.

8.3 Welding titanium

Titanium welds quite well in an inert atmosphere, but any trace of nitrogen, oxygen, or hydrogen in the weld zone causes unacceptable embrittlement. Welding is therefore carried out in an argon atmosphere. This is done by using an argon arc torch to protect the weld pool and mounting the component on a welding fixture with a groove at the back of the weld so that argon can be conveyed to this part of the heated material, and so prevent contamination. This type of welding is eminently suitable for flat sheets and welds. For complicated components, however, it is difficult to make a jig with an argon backing at every weld point, and welding boxes are more generally used. Vickers-Armstrongs (Aircraft) Ltd. are doing considerable quantities of welded titanium components in such welding boxes. Figure 39 shows a welding chamber in use at the de Havilland Aircraft Co. The type of securing jig and the job are shown in the foreground. These welding chambers are made in a variety of sizes to suit components, so that argon, which is an expensive gas, can be used in the most economical manner.

The boxes are of welded construction in mild steel plate with a window of Perspex or shatter-proof plate glass, through which the inside of the cabinet can be viewed by the operator. Manipulation of the welding torch and rods within the chamber is carried out by means of rubber gloves through a sealed opening at the front of the box. The means to exhaust the box by vacuum pump and charge it with argon after evacuation, are provided. The best kind of vacuum pump for this work is the rotary oil immersion type. A high degree of vacuum can be obtained and a single charge of argon after evacuation is satisfactory. The welds produced in these chambers are silvery in appearance and uncontaminated.

8.4 Stress relief

Titanium is a metal which is susceptible to work hardening and fatigue, and where a component has been subject to heavy forming, or welding where high residual thermal stresses may appear, it is subjected to a stress relief heating operation. This is carried out at between 450 and 500° C. in an electric muffle, for a period dependent upon the gauge of the metal involved.

A little titanium is machined for the airframe industry, but a number of machined items are beginning to appear in jet engine design. So far as experimental machining of this material is concerned, it is not the very difficult problem which reading early literature on the subject would lead us to suppose.

9. Sheet metal forming

9.1 Metal working

There have been very few real developments on the metal working side in the past decade. Such techniques as routing and rubber forming, which revolutionised the manufacture of small light alloy components during the few years immediately preceding the War, have not been paralleled in recent years. Developments of these techniques have been made in the form of the Verson Wheelon Press and the Hydroform press.

9.2 Hydroform press

The Cincinnati Hydroform press shown in Figure 40 is in operation at Vickers-Armstrongs (Aircraft) Ltd., Weybridge. Hydroforming enables parts to be deep drawn without the necessity for the conventional type of draw dies. The tools are simple punches. The Hydroform machine is basically a hydraulic press. It has a large hydraulic cylinder and piston in the base upon which the forming punch is mounted. The top dome or pressure chamber is sealed from the work area by a rubber diaphragm and layers of flexible material. The maximum hydraulic pressures in the pressure chamber are in the region of 10,000 p.s.i., but the movement of the piston, punch and work piece into the pressure chamber can increase the pressure to as high as 15,000 p.s.i.

Due to the flexible diaphragm the work is held at all times in intimate contact with the punch as the

punch is made to move upwards. The blank is held in such a way that very deep draws may be made. Unlike normal drawing operations, where the dies are of metal, the surfaces of the components are not injured, and exhibit no draw marks.

Most of the normal aircraft sheet metals can be formed on this type of machine.

9.3 Stretching and stretch wrap forming

These two processes are used extensively and need no introduction. However, there are several minor developments which may be of interest to the Conference. The Folland Aircraft Company are stretch-forming magnesium on heated form blocks. Figure 41 illustrates the inner side of the form block and the component produced. Electric heating elements are secured on the hollow underside. Follands use the formula of 5 kilowatts per 100 lb. weight of tool and the magnesium is formed at 280°C. The component is formed very gradually, in order that heat can flow from the tool into the work piece by direct contact. No doubt a similar technique would be equally suitable on titanium.

Blackburn and General Aircraft Ltd. and Vickers-Armstrongs (Aircraft) Ltd. both use Hufford A.46 forming machines. Both are fitted with the curved jaws which are illustrated in Figure 42. The jaws make the forming of double curvature panels much simpler, and because the material can be made to assume the curved form, a considerable amount of material may be saved.

With flat jaws and severe curvatures, considerable scrap material must be left at the end of the component to enable the material to flow, and even then there is a great deal of slack material at the outer edges of the sheet which makes it necessary to put a great deal more work into the material than would be required if curved jaws were used. The jaws, being able to conform to the curvature on the form block, can be worked very close up to the actual periphery of the component.

Fig. 40. Cincinnati Hydroform press (Vickers-Armstrongs (Aircraft) Ltd.)

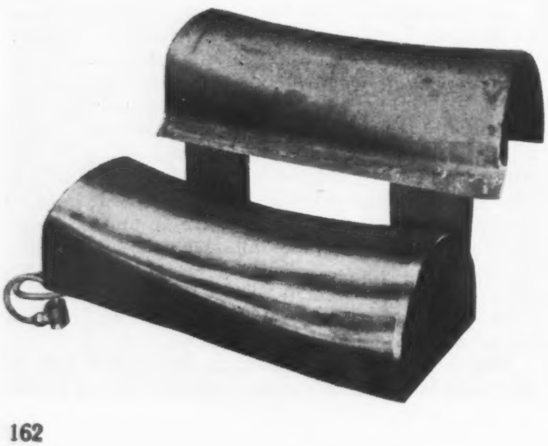


Fig. 41. Heated stretch forming block for magnesium (Folland Aircraft Ltd.)

Fig. 42. Hydraulically operated flexible jaws for Hufford stretch forming press

(Vickers-Armstrongs (Aircraft) Ltd.)

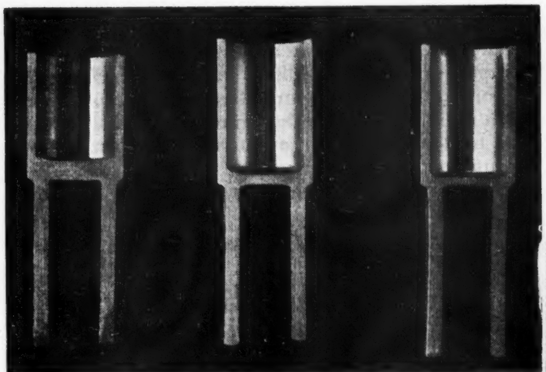


Fig. 43 (above). Fork ends produced by impact extrusion

(A. V. Roe & Co. Ltd.)

9.4 Impact extrusion

A. V. Roe & Co. Ltd. have developed an interesting method of producing their socket components, fork ends and the like. This is by the impact extrusion method. This technique is being developed further to extend its use to other components. A much improved grain structure and surface finish leads to advantages in the fatigue life of the components. The amount of machining is reduced to the minimum. Impact extrusion is a chipless method of producing tubular components, by forcing a punch into a billet located in a die with sufficient force and velocity to cause the billet to flow to the desired shape. Figure 43 illustrates a range of sectioned fork ends produced by this method.

10. Aircraft assembly

10.1 Assembly methods

Methods of jigging vary from factory to factory and are, of course, dependent to a large extent on the design philosophy of that particular company. The Fairey Aviation Co. Ltd. have developed an assembly method known as envelope tooling. Briefly, this means building components from the outside in, rather than building up a structure and skinning as with conventional techniques. All cumulative tolerances are adjusted on the internal structure. The method, which controls the outer profile shape of the components, is fairly well illustrated in Figure 44. It results in extremely accurate profiles.

Fairey Aviation have also designed three-dimensional lofting equipment to simplify the manufacture of this type of assembly jig. Some of this equipment is shown in Figure 45 and provides accurate means for the full three-dimensional laying out of component assemblies.

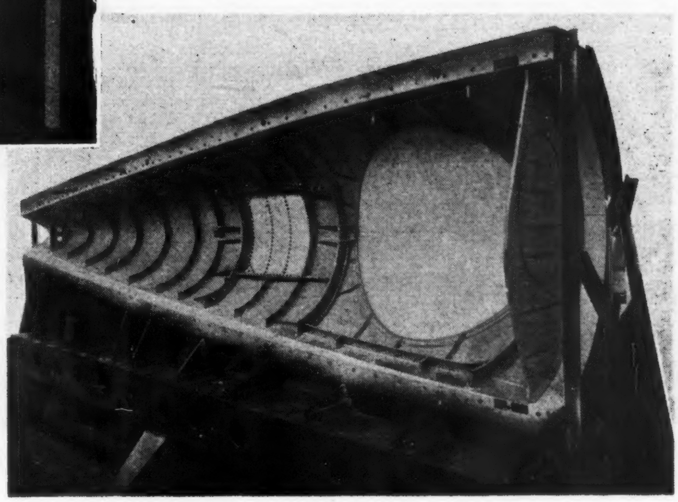


Fig. 44 (right). Typical aircraft assembly in an envelope jig

(Fairey Aviation Co. Ltd.)

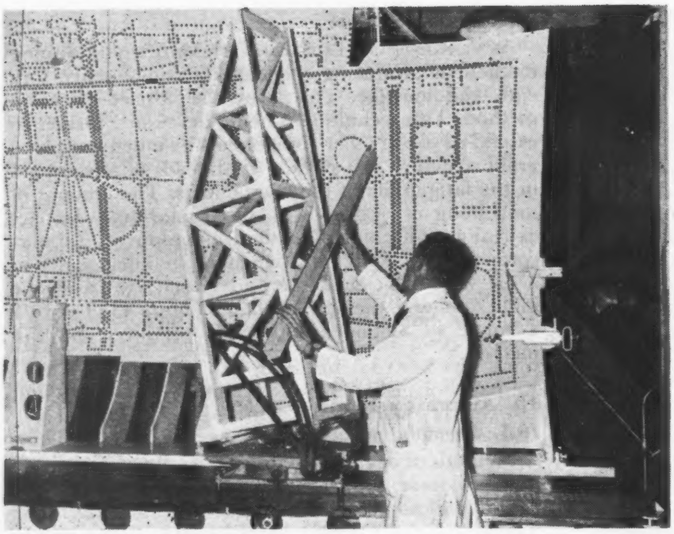


Fig. 45. Use of the Fairey three-dimensional lofting equipment for marking out jig skins (Fairey Aviation Co. Ltd.)

Drill gates and contour control profile masters can be made from glass cloth resin reinforced lays or stretched form steel or light alloys. Glass-cloth is the more simple method as these can be taken directly from a plaster master form.

10.2 Handley Page Ltd. have adopted the design philosophy of spot welded structures, which they regard as cheaper, and which give a higher surface finish, than the more normal riveting techniques. It is also claimed that spot welding leads to lower cost and lighter structures. Figure 46 shows typical spot welded assemblies, that of a fuselage panel and a nose skin. They produce their stringers and drawn sections to very fine limits in order to ensure accuracy of assembly. The stiffeners shown on the nose skin are used for de-icing passages. The technique also leads to the manufacture of sandwich construction in which a corrugated form is spot welded to the outer skin, the inner skin being blind riveted to the tops of the corrugations, making a very stiff, strong structure. This is used for wing planks and fuselage sections.

Figure 47 shows the continuous seam welding machine which Handley Page Ltd. are using for welding stringers and structures. They have paid great attention to the maintenance of high quality spot welding by means of rigid quality control. They are spot welding primary structures on both the Victor and the Herald Aircraft.

10.3 Puddle welding

Puddle welding, formerly available commercially as argon arc fusion welding, has been developed by Bristol Aircraft Ltd. Figure 48 shows a stainless steel beam manufactured by the Company by this process. The heat source is an arc struck between a non-consumable tungsten electrode and the work. The electrode and the weld area are shielded by an inert

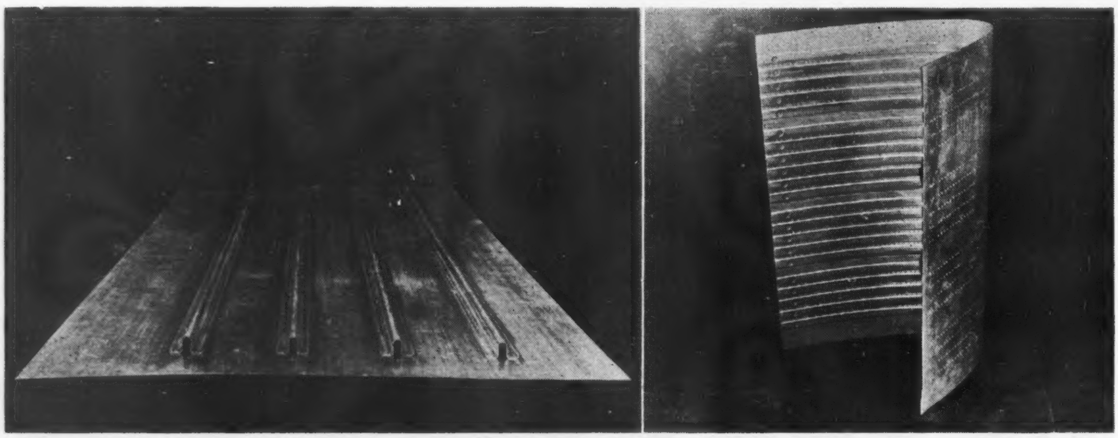


Fig. 46. (a) spotwelded panel; and (b) nose skin (Handley Page Ltd.)

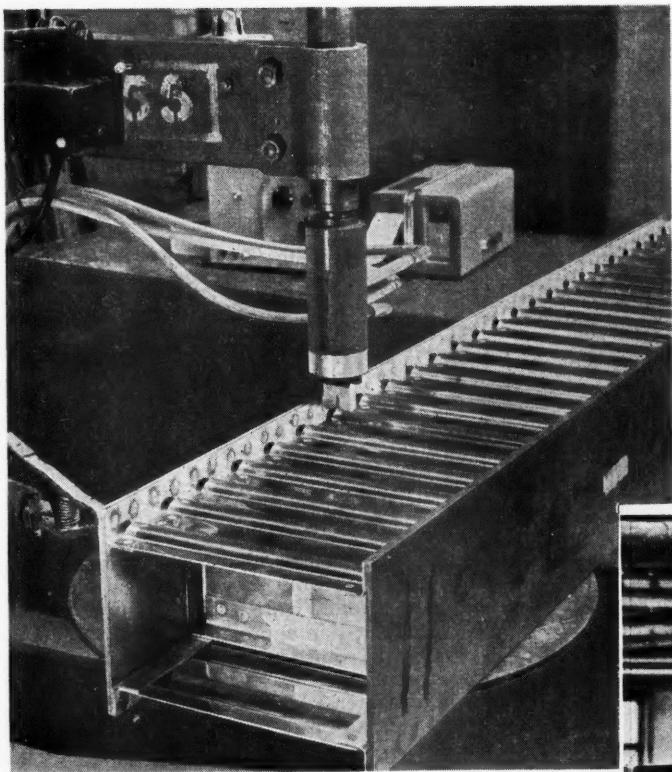
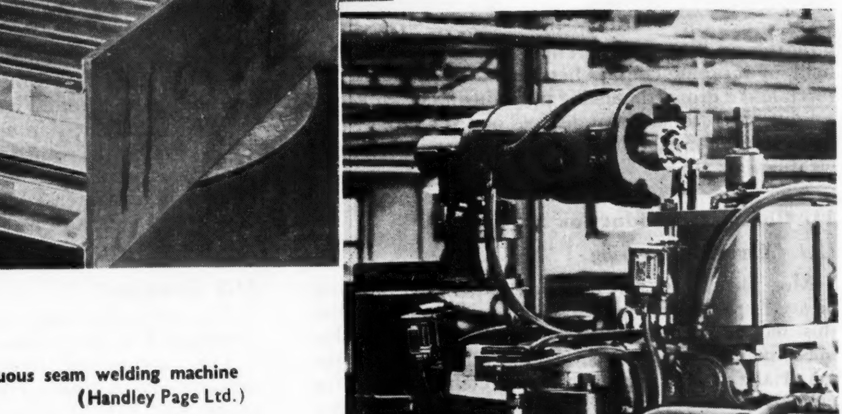


Fig. 48. A puddle welded assembly in stainless steel

(Bristol Aircraft Ltd.)

Fig. 47 (right). **Continuous seam welding machine**

(**Handley** Page Ltd.)



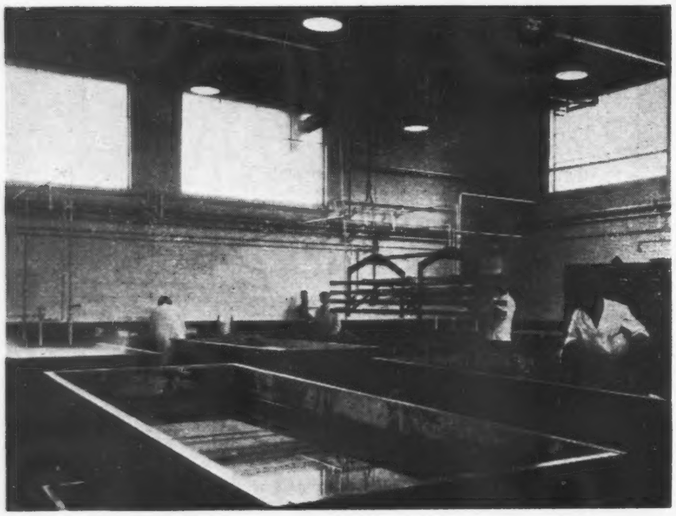


Fig. 49. Chemical contouring plant
(Vickers-Armstrongs (Aircraft) Ltd.)

atmosphere of argon gas. The sheets to be welded are held in intimate contact between the shroud of the torch and a grooved backing plate during welding and solidification. The electrode does not touch the work, and there is no forging action as in resistance spot welding.

11. Chemical production methods

11.1 Chemical contouring

Most British aircraft firms are experimenting with or are in production with chemical contouring. With this technique, a part is protected by a suitable maskant in certain areas, leaving other parts of the material exposed. Immersion in an etchant causes the material to be eroded away in the unprotected areas. This is a considerable advantage with formed components, since these may be etched in the formed state, thus avoiding the difficulties which are experienced in forming a component with a non-uniform cross sectional area. Figure 49 shows a typical chemical contouring set-up and Figure 50 a typical aircraft part. This is a tailplane skin approximately 6 ft. in length by 2 ft. wide. The etched areas are of different depths, and this is accommodated by progressive de-masking of the exposed areas. United States practice uses a Neoprene base paint as a maskant, but some British practice has followed different lines.

11.2 Technique

The technique employed at Vickers-Armstrongs (Aircraft) Ltd. is as follows:—

The part is first thoroughly cleaned, and then sprayed with a plastic film which has few adherent properties. A light alloy template is laid on to the workpiece and the areas to be etched are cut through with a model knife, piercing the plastic film but taking care not to scratch the component material. The areas

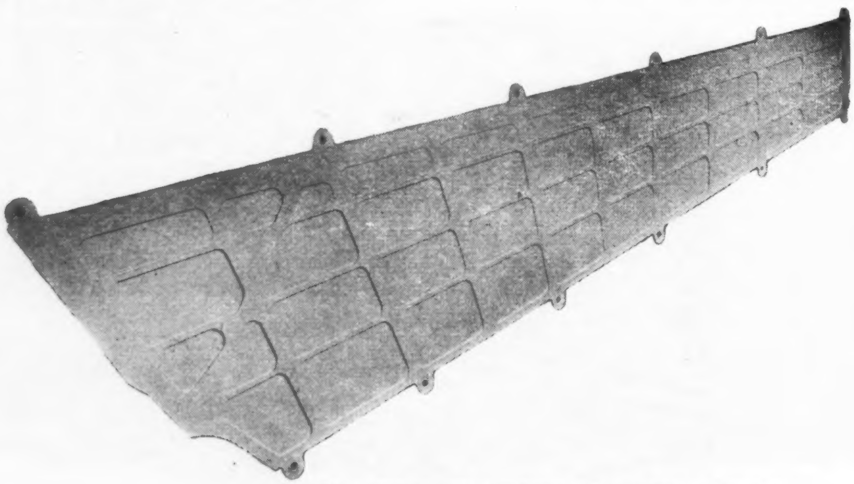


Fig. 50. Tailplane skin produced by chemical contouring
(Vickers-Armstrongs (Aircraft) Ltd.)

to be protected are then stripped of the plastic film which comes off easily in one piece, leaving the area to be etched with the plastic film still in position. A priming coat, followed by two coats of an epoxy resin paint, are applied and it is then cured by stoving at a comparatively low temperature. When dry, it is easy to lift the corner of the protective film in the areas to be etched, and to strip away the whole of the film and paint coat, leaving an extremely sharp edge.

The epoxy resin is very adherent to the base metal. The plastic film has little or no adherence, but a fairly high tensile strength and flexibility, so that the area can be stripped in one piece.

The component is then immersed in a 15% solution of caustic soda operated at 85°C. for a period of time which is dependent upon the depth of etch required. The etching process is uniform over the whole surface and varies from ·040 in. to ·060 in. per hour. The part is then washed, immersed in a de-oxidising bath, washed again; the paint is removed and the part is then inspected and anodised.

11.3 Fatigue

Some firms carry out a post-heat treatment in order to minimise the risk of loss of fatigue life through hydrogen embrittlement. Fatigue tests have shown that the scatter on chemically eroded specimens is very much less than that on similar machined items. A greater overall degree of accuracy can be obtained with chemical erosion than by machining.

11.4 Etching template requirements

In manufacture of the templates, some allowance must be made for the fact that the etch proceeds sideways as well as downwards, and therefore the templates must have an allowance on them equal to the depth of the etch. A radius at the edges of the pockets is produced which is a function of the depth of etch. This is a helpful feature because of stress distribution, but does somewhat limit the depths to which the etch can be satisfactorily taken.

No hand finishing is necessary on chemically contoured specimens. Since the paint material is

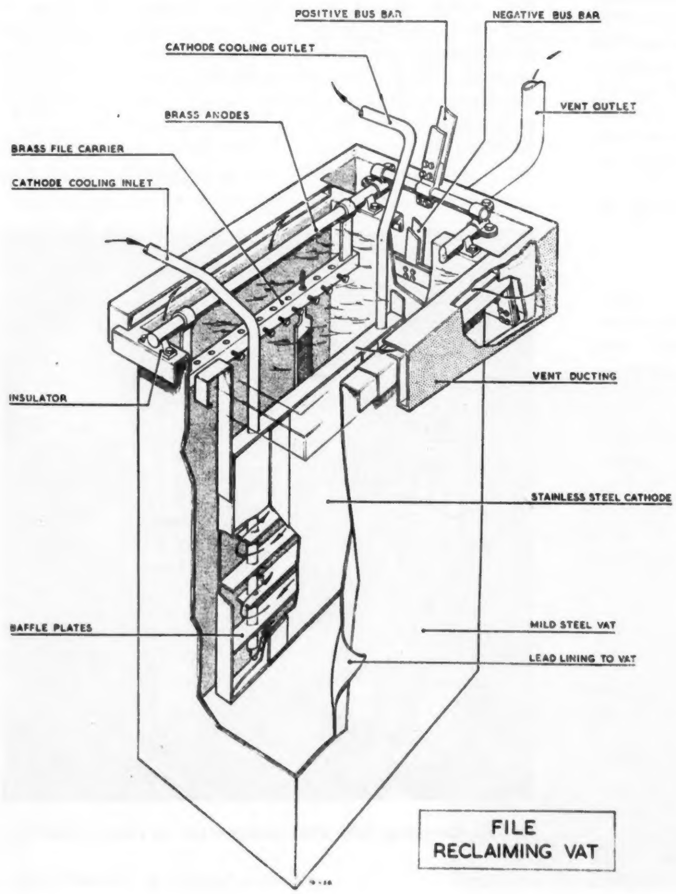


Fig. 51. Design of vat for the file reclamation process
(Vickers-Armstrongs (Aircraft) Ltd.)

flexible, the part can be formed after masking and etched in the fully formed state. The etchant used can be reclaimed by a seeding process and used over and over again.

Chemical contouring shows a significant economy over machining methods, especially since a polishing operation is generally needed to smooth machining marks. For example, the following savings have been achieved at Vickers-Armstrongs (Aircraft) Ltd. Taking machining times as 100% rudder skins are done in 19·5% of the time, aileron skins 25·3%, fuselage panel 67%, access panel 80% and tailplane skin 32%. The larger and more complicated the pocket areas, the greater are the savings.

Experiments are now under way to apply this type of process to the contouring of titanium and alloy steels. This has been done successfully in production in the United States, to limited depths, but has not been brought to that stage of development in the United Kingdom at the moment.

11.5 Chemical reclamation of worn files

Vickers-Armstrongs (Aircraft) Ltd. have developed a process which enables used files to be reclaimed and which is illustrated in Figure 51. By this method, a worn file is immersed in a bath of 56% sulphuric acid, and a voltage is applied between the bath and the file. Subsequent electrolytic action causes preferential erosion of the flank of the file teeth, thus causing a fresh cutting edge to be formed. Heavy milling cut files can be reclaimed up to seven times, and the cost of the process is negligible. The voltage is about eight and the current load for a 10 in. file is 100 amps. An application for ten minutes is sufficient to reclaim the average file. In the tank shown twelve files can be processed at once.

11.6 Electrolytic profiling

The same firm is developing the use of electrolytic erosion for the production of components and templates. The part is drawn out on stable material, and then photographed. A photo-sensitive mask is applied to the template or the part, and developed using the photo-negative. The part is then immersed in an electrolyte in a bath, and an electric current reverse plates those areas which are exposed, etching through the material to produce the part. The process is not at the moment in an advanced state of development, but there is the possibility of a new technique for the production of parts and templates without using standard metal cutting techniques.

12. Spark erosion

Spark erosion of hard metals is also receiving a great deal of attention. The process is already in use for the production of dies, the drilling of holes in hard materials, and similar small scale machining operations. What the present development seeks to do is to increase the present cutting rate of the process 10- or 20-fold, with a parallel reduction in the rate of erosion of the electrode. If this can be satisfactorily accomplished, then the machines can be designed which will take their place alongside normal machine shop cutting tools. The advantages of this method are that even the hardest of materials may be machined provided they are electrically conductive.

13. Relief of stress raisers

13.1 Metal finishing

With the advent of high strength materials and increasing quantities of machined items, fatigue becomes an important consideration. Most machine marks can be regarded as potential stress raisers, especially on areas where alternating tensile stresses are applied. As a consequence, it is necessary to apply some finishing operation to remove certain machine marks. On high strength steels this problem becomes more acute, since with the hardness of the material the machine finish obtained becomes progressively worse and the notch sensitivity becomes greater.

13.2 Barrelling

For many years past the British aircraft industry has used the barrelling technique for the removal of machine marks and stress raisers. One of the advantages of this method is that all edges are rounded, and since sharp edges are in themselves potential areas of high stress, this is advantageous. Figure 52 shows a typical barrelling process. The components are located in fixtures which are loaded into a drum which can be rotated. Chips are then loaded into the barrel, together with an abrasive and foam producing powder, followed by the addition of water to a depth sufficient to cover the load. The barrel is then rotated for a period dependent upon the hardness of the

Fig. 52. Barrelling light alloy components to remove machine marks

(Vickers-Armstrongs (Aircraft) Ltd.)

material, the chips, the load, etc. In rotation, the mass of chips and abrasive in the barrel flow over the work and smooth out the imperfections. This is a typical machine operation and replaces hand polishing.

13.3 Vapour blasting

Another method of stress relief is by the use of vapour blasting. By this process a slurry consisting of water and a fine abrasive compound is pumped through a nozzle and air pressure is injected, which accelerates the mass. This jet is directed upon the workpiece and the abrasive, peening and compressive effect on the surface greatly increases the fatigue life of the material.

There are other methods of application of vapour blasting, some of which use a rotating drum to accelerate the mass of abrasive slurry to work upon the surface of the component. Some aircraft firms employ shot peening for the relief of stress raisers. Short Brothers & Harland Ltd. have done considerable development work on this process and employ very fine shot and a special impelling device to produce a very close surface in compressive stress.

14. Manufacture of steel wind tunnel models

14.1 Model making

Most of the large aircraft companies in the United Kingdom have set up model-making shops for the production of high speed wind tunnel models in steel and high strength materials. These models have to be made to very fine accuracies, and their production is a completely new technique in itself. A high degree of operator skill is necessary, together with the use of sophisticated milling machines, etc. There are several ways of producing the aerofoil and fuselage profiles.

On an aerofoil which is of uniform or straight conic section, tangent plane machining methods can be send. By this method, the component is set up on a compound sine table, and the work is presented to the cutter or the grinding wheel in a series of flat planes, the angles of which have been previously calculated. A number of these machined planes will approach the final form very closely, so that only the minimum of hand dressing is required.

Another wing form has a varying profile throughout the section. Although there are straight line generators, these cannot be developed in the form of flat planes, and the method of approach in this case is to machine a series of steps. The centre of the "V" in each step is the straight line generator in that particular plane. Dressing then takes the form of removing the material down to the witness marks at the "V" of the step.

Another wing form embraces changes in profile and in twist. There are no straight line generators here, and the basic form of the wing can be machined by milling a series of facets. These facets are mathematically worked out and machined using a sine table on a jig borer. A sufficient number of facets are machined on the wing plan form, so that final dressing takes the form of removing the excess material and leaving a witness mark at the centre of the machining.

A further method which is applicable to all three is to use the vertical copying technique. With this, a master pattern is required and uses a servo operated copying head to transfer this master pattern, by means of stylus and hydraulic valve, to make the milling head traverse the profile of the wing form. These master patterns may be made in densified wood or they may be made by building up a block of templates, corresponding to the ordinate positions of the wing form, and casting in a synthetic resin to fill up the spaces between the templates. The resin is then hand-dressed to the template forms to produce the desired master.

Fuselage forms may be produced by the copying technique from a master pattern or the fuselage may be turned. Turning is done on a special type of copying lathe. A full three-dimensional pattern is

Fig. 53. Honeycomb, Reduxed, sandwich panel (A. V. Roe & Co. Ltd.)

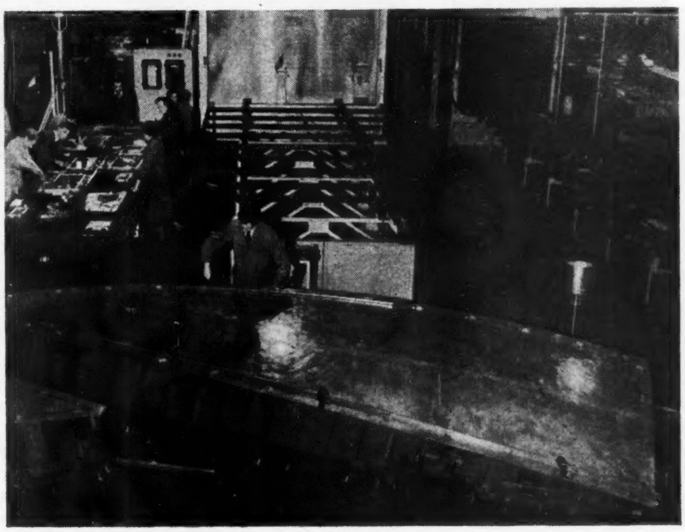


Fig. 54. **Reduxed beam**
(Bristol Aircraft Ltd.)

made to rotate at the same speed as the work piece, generally at about from $1\frac{1}{2}$ to 10 r.p.m. A stylus operating a hydraulic valve causes the tool holder to move in sympathy with the path travelled by the stylus over the pattern, thus reproducing the form on to the work piece. This method of producing fuselages is very accurate indeed, and will trace out double bubble shapes, canopy forms and so on.

Model templates are produced in a number of ways. In order to achieve the necessary accuracy, the master form is drawn to a magnified scale on stable material. Using a 20: 1 magnification and a pantograph controlled grinding head, the form of the template can be accurately ground within $\pm \cdot 0003$ in.

Another method is to hold the template in the light path of a projection machine, and a magnified image on the screen can be matched against a scaled up profile drawn on transparent stable material; the template profile being dressed whilst in position to make it conform to the drawn line.

15. Stainless steel honeycomb and metal adhesive bonding

15.1 Metal bonding and honeycomb-cored structures

Many aircraft companies are making use of metal adhesives in the manufacture of primary structures—Bristol Aircraft Ltd., de Havilland Aircraft Co., A. V. Roe & Co., Vickers-Armstrongs (Aircraft) Ltd., are some of the major firms. The techniques vary between the companies, insofar as the actual bonding methods are concerned. Some use electrically heated muffles, others steam-heated presses, and others steam-heated autoclaves. Most of the major companies use a combination of all three. The extent to which the development of the honeycomb sandwich has been taken in this country, can be seen in the photographs which illustrate the procedure. Figure 53 shows a honeycomb sandwich panel which is manufactured at A. V. Roe & Co., and Figure 54 a large beam, the stiffeners of which are Reduxed to the web plates, made by Bristol Aircraft Ltd. for the Britannia.

15.2 Stainless steel honeycomb

Higher Mach numbers must inevitably bring an increasing use of steel into aircraft and missile construction. Stainless steel sandwich construction employing honeycomb core is recognised as one of the most efficient methods of fabricating these structures with the least weight penalty. The brazing of steel honeycomb is an extremely difficult task, but A. V. Roe & Co. have successfully tackled and manufactured extremely large structures. Figure 55 illustrates a cylinder which is 6 ft. 4 in. in diameter, and which was brazed in one piece. The outer and inner facings are of stainless steel as is the core. The stainless steel was especially developed for A. V. Roe & Co. by Firth Vickers, and it is a chrome nickel copper molybdenum stainless steel of the precipitation hardening type, designated FV.520.

One of the difficulties associated with the brazing technique is the temperatures which must be attained. This causes oxidation of the surface of the metal and brazing will not take place. A great deal of development work has gone on at A. V. Roe & Co. in order to overcome these difficulties. The components to be brazed are sealed in "coffins", which are purged thoroughly with nitrogen and then a gaseous flux is introduced. It is necessary that a special type of honeycomb is used in order that each cell shall be able to breathe, so as to get rid of all the air. The brazing takes place in large electrically heated furnaces and after this operation nitrogen is again introduced to blow out and clear the "coffins" of the gaseous flux. Figure 56 shows a specimen of a leading edge made by this brazing technique. Other firms experimenting with brazed steel honeycomb structures, seal the components in "coffins" and evacuate by vacuum techniques, afterwards filling with argon gas. The brazing is carried out in this inert atmosphere.

Fig. 55. Stainless steel brazed honeycomb cylinder (A. V. Roe & Co. Ltd.)

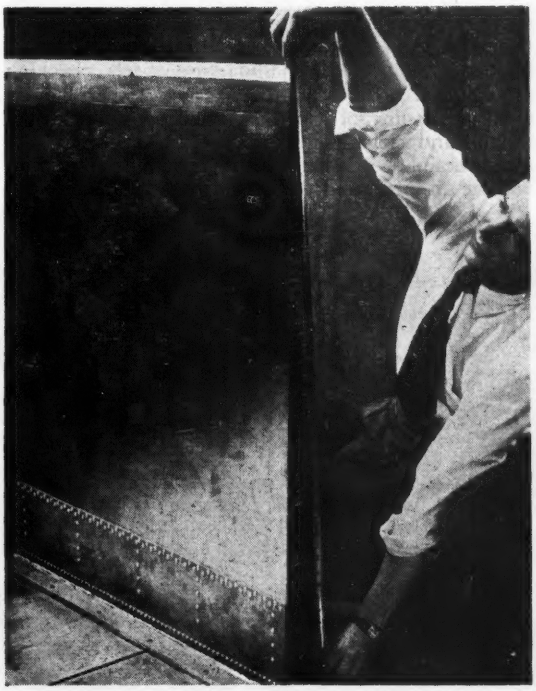


Fig. 56. Stainless steel brazed honeycomb structure — section of a wing leading edge (A. V. Roe & Co. Ltd.)

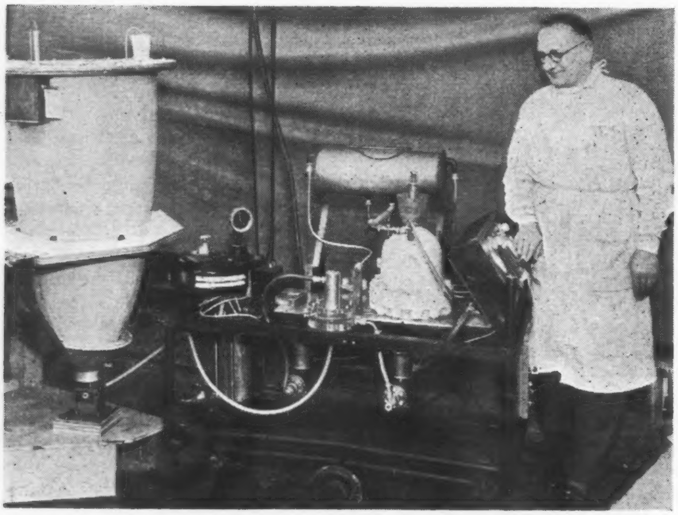


Fig. 57. Injection moulding a glass fibre resin bonded radome shell
(Bristol Aircraft Ltd.)

16. Plastics

16.1 Plastics—resin-bonded moulding techniques

Most of the British aircraft firms are using considerable quantities of plastic material for tooling purposes. Plastics are being used for drop hammer tooling, rubber die tooling, ironing caps for rubber die tools, hammer form blocks, dressing blocks, etc. Glass cloth resin bonded laminates are being used for the manufacture of drill gates, profile plates, routing templates, chemical erosion templates, and so on. Wide use is being made of reinforced glass cloth laminate resin bonded tubing for the manufacture of jigs, checking fixtures, etc. It has been found to be very satisfactory from the point of view of making modifications, repairs and changes, etc. It is light—it is virtually indestructible—it is stable, and no doubt the future will see an increasing use of this material. Glass cloth laminates can and are being used for the attachments of aircraft canopies, and an artificial fibre cloth terylene of great strength is also being used for a flexible edge attachment for canopies.

16.2 Injection moulding glass fibre

Bristol Aircraft Ltd. have been experimenting with automatic injection methods for the manufacture of fibre glass resin bonded mouldings. The methods used show the way to the automatic and economic production of components in large quantities while maintaining a high standard of dimensional accuracy, coupled with consistency of moulding. Figure 57 illustrates an experimental set-up for the injection moulding of a radome shell.

Bristol Aircraft Ltd. have designed and are manufacturing large quantities of asbestos phenolic resin bonded drop tanks. The tanks, which are nestable for

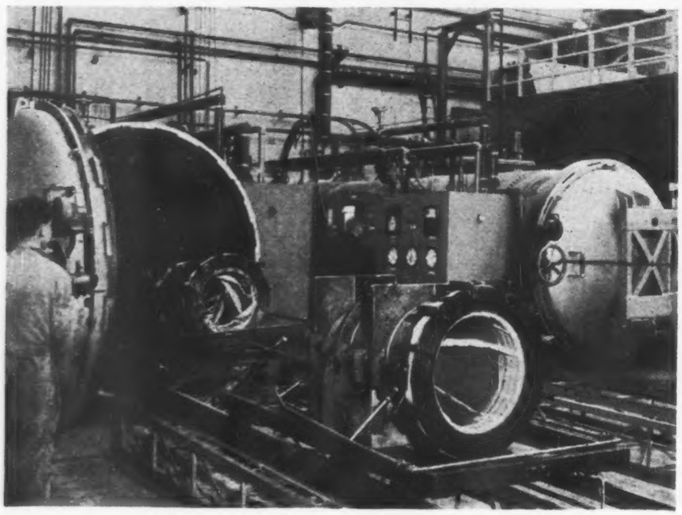


Fig. 58. Autoclave method of curing asbestos phenolic resin bonded drop tanks
(Bristol Aircraft Ltd.)

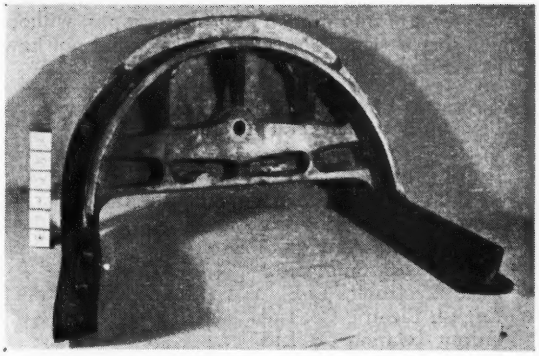


Fig. 59. A canopy member made from fibreglass moulded laminate

(English Electric Co. Ltd.)

ease of storage and transport, are made by the autoclave method. The pre-impregnated asbestos felt is laid up in aluminium tools and cured at a temperature of 150°C. at a pressure of 100 p.s.i. for 20 minutes. Figure 58 illustrates a pair of jigs being inserted into the autoclave and shows the way in which pressure is applied to the moulding through a flexible inner lining to the tool.

16.3 Vacuum forming of canopies

Most of the large companies in Britain now produce their canopies by vacuum forming techniques. Up to a few years ago, most of these were produced by grease forming, that is by using a mould covered with glove fabric and flooded with molten grease so that when the heated Perspex was draped or stretched over the mould, a hydraulic film prevented the mould from marking the canopy. However, good optical properties were very difficult to obtain by this method, and with the redesign of canopies to obtain true circular cross sections, which incidentally were better also for pressurised cockpits, it was possible to use pressure forming techniques.

By the vacuum forming technique developed, a heated Perspex blank is draped into a forming box and suction is applied. External air pressure then forms the Perspex into the desired shape. The heated Perspex does not touch any form block, the only restriction being at the edges of the canopy where it is to be attached to the metal frame, thus securing the peripheral shape. The resulting canopies have very good optical properties, and much time is saved by reducing the amount of hand polishing which is necessary.

16.4 Glass cloth airframe components

Figure 59 shows a canopy rear arch member for the Canberra Mk. 9 aircraft, made from fibre glass moulded laminate. It was originally designed to be machined from a D.T.D. 304 casting. The estimated machining time was 40 hours. As a moulding in glass cloth, it shows a considerable saving in time. It is moulded to size using Y.346 twill weave ·007 in. laminate, loaded into a die and pressure impregnated using Marco resin SB.28C.

16.5 Plastic tooling

Quite a number of firms are using plastic tools for the manufacture of small batches of components. They are very easily and quickly made and show an economy over manufacture by machining methods. Figure 60 illustrates two different types of tools made

Fig 60 (a) and (b). Use of plastics for the manufacture of tooling

(Saunders Roe Ltd.)

by Saunders-Roe Ltd. One is made in an aluminium filled plastic compound, and this is used for the deep drawing of stainless steel. Die, punch and pressure plate are all in the metal filled plastic compound. The other is a simple epoxy resin tool for forming the component shown, on a rubber die press.

Conclusion and acknowledgments

As much as any other, the British aircraft industry is vitally aware of the need for continued improvement of existing methods and the development of new production techniques. Almost every company has accordingly established a Production Development Department, not only to consider and develop new and improved processes, but to effect the widest possible dissemination of knowledge among production personnel. There is ample evidence that the principle of co-operation in this sphere has been and is being applied, not merely inter-departmentally, but throughout the companies of the industry as a whole. The attendant advantages of the continuance of such a policy need not be stressed, but I would here like to acknowledge, with gratitude, the unstinted assistance given by the under-mentioned companies in the form of information and photographs, without which the presentation of this Paper would not have been possible:

"Aircraft Production"
Blackburn and General Aircraft Ltd.
Bristol Aircraft Ltd.
British Thomson-Houston Co. Ltd.
C. J. C. Developments (Portsmouth) Ltd.
Cramic Engineering Co. Ltd.
de Havilland Aircraft Co. Ltd.
E.M.I. Electronics Ltd.
Ekco Electronics Ltd.
English Electric Co. Ltd.
Fairey Aviation Co. Ltd.
Ferranti Ltd.
Folland Aircraft Ltd.
Handley Page Ltd.
Industrial Technics (Southampton) Ltd
J. L. Jameson Ltd.
"Machinery".
Morfax Ltd.
A. V. Roe & Co. Ltd.
Saunders-Roe Ltd.
Short Bros. & Harland Ltd.
Vickers-Armstrongs (Aircraft) Ltd
Wadkin Ltd

REPORT AND DISCUSSION

Chairman: E. F. GILBERTHORPE, A.M.I.Mech.E., M.I.Prod.E., A.M.B.I.M.

MR. **Burnard,** in presenting his Paper, said that he did not propose to read it, but proceeded to summarise and amplify some of the main points of development brought out in the Paper. During this talk he said that he had lately visited the United States and had had the opportunity of examining some of the main differences between American and English techniques. One of the objects of the visit was to look into the methods by which the American industry carries out machining of high tensile steels. He said that he had discovered no new techniques for the machining of these high strength steels. Where copy milling using end mills was employed, the Americans used high speed steel cutters with surface speeds of up to 50 ft. per minute and feeds from .002 in. to .008 in. per tooth depending on the diameter and slenderness of the cutter. This was comparable with English practice.

What was, however, surprising, was the wide use by the Americans of fabrication by welding. Very large components which would be difficult to make by machining from a forging or a billet were fabricated in this way and without a significant decrease in the tensile strength. These components were being welded with heat treatable welding rods and strengths obtained of 200,000 lb. per sq. in. and over. By the correct positioning of the welds in areas of low stress, etc., they were very often able to keep the strength of the component to that of the parent metal.

Another practice which the Americans employed was the machining of high strength steels in the annealed or semi-hard condition, the machining being completed to finished size in this condition. A method of controlled heat treatment using inert atmosphere furnaces and a subsequent stress relief and temper draw on special jigs designed to eliminate distortion, brought the finished components to the required strengths without distortion, oxidation and de-carburisation.

Mr. Burnard said that he did not believe that the British were behind the Americans in basic ideas in design, original thought, or manufacturing techniques. Most of our production methods in the manufacture of details were similar. There were, however, some fundamental differences in assembly. The Americans excelled in pre-planning, everything being very carefully thought out beforehand. Production brochures were produced well in advance of production, outlining in detail all the methods to be used, times of production, schedules, factory layout, manufacturing sequences, etc. The British could, with advantage, follow this procedure.

The American assembly lines were models of pre-planning. All these differences might be the effect of quantity, it being easier to amortise the very heavy cost of a mechanised assembly line over a large quantity of aircraft. Despite all this, it was probable that costs in Britain and America were not so very different. The differences in the quantities of aircraft to be built inevitably led to different methods of tackling the job, and that was one of the reasons why Mr. Burnard thought that he found more extemporisation in Britain than in America.

Mr. Burnard went on to discuss the developments under way in the U.K. on the possibility of routing high tensile steels, and exhibited a component which had been loaned by the Gloster Aircraft Co., and which was produced by routing. The firm carrying out the development for Gloster Aircraft Co. was Messrs. Farrand Luttmer, of London, using a patented process of CO_2 feed and tool design — the router head using a speed of 4,000 r.p.m.

Mr. Burnard showed a film illustrating a number of the new production techniques outlined in his main Paper, and then called upon Mr. H. G. Gregory, of Fairey Aviation Ltd., to show a colour film which his Company had

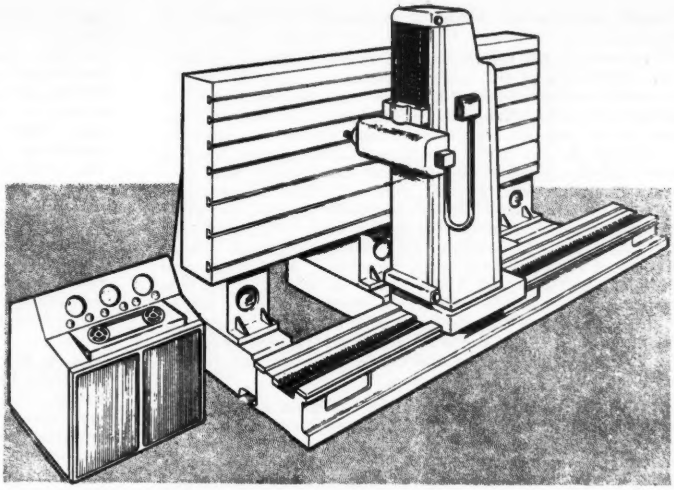


Fig. A.

produced, illustrating the numerically controlled milling machine which had been developed by them. The machine had programmed numerical control on all three slides, designed by Messrs. Ferranti Ltd., of Edinburgh.

Mr. H. G. Gregory, M.I.Prod.E. (*General Manager, The Fairey Aviation Co. Ltd., Stockport*), expressed thanks for the opportunity of being able to show to a senior assembly of production engineers what he regarded as the latest development in a numerically controlled machine tool. Two years ago Mr. Vines and he had given a Paper on the theme of " Time Can Be Saved in the Aircraft Industry" and at that time showed a slide on what they thought would be the machine tool of the future.

He again presented this slide (Fig. A), which showed their concept of the machine. Although at that time they had not gone much further than thinking about it, since then, however, the machine had been built. They had a contract in October, 1955, backed by the Ministry of Supply. Mr. Hollis had been intimately concerned in it.

A fortnight ago, Mr. W. E. Goff, the Editor of "Aircraft Production ", arranged for his artist to see this machine and his work would be published in " Aircraft Production ". The slide of the artist's drawing was then shown (Fig. B). They would see how closely the machine resembled their original thinking. The operating area was 24 ft. by 7 ft., and the gross weight of the machine about 50 tons, and maximum travel on the " X " axis was 120 in./min.; the control of the machine was by magnetic tape; the column weight was about 7 tons.

A colour film produced by the Research Unit at The Fairey Aviation Co. Ltd., Heston, was then shown and was enthusiastically received.

Mr. W. S. Hollis, B.Sc., A.F.R.Ae.S., M.I.Prod.E. (*Assistant Director, Ministry of Supply*), opening the discussion, said it was a great tribute to Mr .Burnard that other firms had contributed so much detail ; it was also a great tribute to him that in a relatively short Paper he had

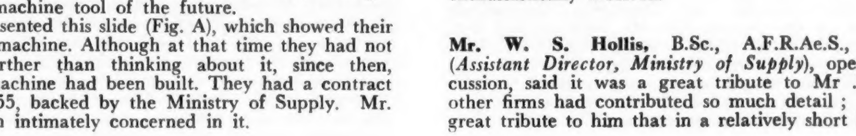


Fig. B.

covered almost every phase of production development in the U.K.

Facilities for the use of large stretched levelled slabs were now available, and this material would be used extensively. It would be remembered that three years ago, at a previous Conference in Southampton, it was made abundantly clear that stretch levelled slab was wanted, and it was pleasing to see that the two firms, Northern Aluminium and Booth's, who had done much in providing the means, had now met industry's needs. He felt, however, that the optimum shape of this material had not yet been reached. In using material in rectangular slabs, it was fairly evident in the larger sizes and in particular for wing panels, that a huge amount of material had to be removed ; Mr. Bucey and Mr. Burnard had said it amounted to 80%. It was the business of the aircraft industry to produce aircraft, not to produce chips; and some effort should be made towards the production of rolled stretched stabilised tapered material. He considered it could be done, and every encouragement should be given for its production.

He had been pleased to see in the Paper acknowledgment and encouragement of the smaller firms who worked on the fringe of the aircraft industry; sub-contractors who had fought their way into integral production by employing machines which they themselves had built or improvised with the assistance of such firms as Wadkin and Cramic. Some were doing the same for integral methods in steel.

In the detailed design of machine tools, particularly in the heavy duty type, he found that rigidity and response factors were becoming increasingly important. Materials of increasing shear strength were continually coming forward, and designers must deal effectively with this and with the slideway displacement rates which numerical control could offer. In addition, the question of the dynamic stability of the machine tool had to be considered. A fair amount of work had been done both in Germany and in America on the rigidity and dynamic stability of the workpiece and the machine tool. For the Ministry's part, they were about to encourage work of a research character to assist in this field.

Stretch wrap forming was becoming increasingly important and he was pleased that Mr. Burnard had been able to illustrate the curved jaws which had been a joint development with his Organisation, who were interested in the savings which could be obtained both in the construction of the unit in the U.K. and in the saving of material when the jaws were put to work.

The Paper had referred to titanium. The material had brought its problems and Mr. Hollis felt that, on the whole, industry had too casually dismissed many of these. It was true that tool life had been improved considerably. Forming of commercially pure material was reasonably straightforward and resistance welding gave rise to no problems. In the overall picture, however, titanium costing about £6 a lb. was in its fully fabricated form costing £22 to £30 a lb. Any reduction in price of the raw material could only affect total costs marginally and it was essential to concentrate on better manufacturing methods if costs were to be reduced substantially.

In particular, Mr. Hollis thought that economies could be effected in those directions in which chipless production could be used ; in the manufacture of standard parts — bolts, fastenings and so on.

Mr. Burnard in reply thanked Mr. Hollis. Vickers-Armstrongs (Aircraft) Ltd. had carried out no specific tests on the wear rate of tools on light alloys. Using mist lubricants to avoid cutter pick-up and smear, they achieved cutter lives between regrinds of almost a week's working. Since they had such good results, they had taken no steps to investigate wear rates. They were using cemented carbide cutters with the tool bits brazed on to .5% carbon steel bodies. They had done a very little titanium machining, and they had not machined any titanium alloys. They had found no difficulty in the machining of pure titanium. Perhaps some members of the audience were more qualified to talk about the machining of alloyed titanium, and they might be induced to add to these comments.

Mr. G. H. Taylor (*Aircraft Development Engineer, The English Electric Co. Ltd.*), referring to alloyed titanium, said they had been carrying out an exercise for the Ministry of Supply on RC/C130AM material. Cutting a large forging about 5 in. square, at 180 ft./min. with carbide tools, a tool life had been in the region of four hours between regrinding. Other firms had taken a selection of small stampings, and these had been practically uncuttable. But the large forging, with which conditions they and Boulton and Paul were associated, presented no serious cutting difficulty. On inquiry from the people responsible for the forgings, he had discovered that they had been forged straight down from a 6 in. billet without any scalping between each heat, and embrittlement had occurred. This had made the forgings uncuttable. It was better to reduce by cutting into small, suitable sizes for forging rather than try to hammer down, or else to scalp after every heat.

Mr. A. W. Rogers (*Engineer II, Ministry of Supply*), said that Mr. Burnard had spoken of a method he was investigating, which apparently was one of applying sequence control to a capstan lathe. Was this a refined method whereby the tools set themselves ? Did he know that a system was already going into production in this country where, by the application of electro-hydraulic sequence control, with an air-operated chuck, an ordinary capstan lathe could virtually become an automatic machine ?

Mr. Burnard replied that the problem in the industry at the moment was the manufacture of very small batch quantities, such as 10 off. It might take 100 minutes to set up a capstan for the production of only 10 off, which took perhaps half-an-hour or so, and it was found better to allow the setter to produce these than to put an operator on the job. If it were possible to produce a capstan which set itself, then the setting time could be eliminated. That was the problem they were investigating at the moment.

Mr. S. P. Woodley, M.B.E. (*Director and General Manager, Supermarine Division of Vickers-Armstrongs (Aircraft) Ltd.*) said that Mr. Burnard had not explained what he, Mr. Woodley, wanted. What he intended to get was a machine which would set itself with the use of a punched card, run off 10 components, and finish. That was the ultimate to which they were working. They wanted a punched card produced in the Design Office with information regarding the numbers to be produced, date on which they were to be produced, and all the numerical information for setting the machine. The machine would then do its own planning and produce the component.

Mr. Burnard said that this showed the problem they were up against. What they were working on at the moment was a slide under numerical control in which the tool was clamped without reference to any datum. On the tool moving in to the cutting position, it passed a datum setting device, when numerical counting would start under control of the punched card. This count would then produce the desired diameters. They had reached this position at the present time but the problem was to integrate this into a complex of slides, capstan and bar movements.

Mr. L. F. Chambers (*C.J.C. Developments, Portsmouth*) referred to the Fairey three-dimensional lofting equipment in Fig. 45 of the Paper and asked Mr. Burnard to enlarge on his description and to say whether the equipment could be used for machined components of a complicated nature.

The **Chairman** explained that two years ago Mr. Vines and Mr. Gregory had given a Paper on the subject, but if Mr. Gregory wished to contribute to the discussion he would be welcome.

Mr. Chambers said he remembered the Paper, but he wanted to know whether the machines could be developed in respect of machined components. Any lofting done for machined components was still lofted in the flat plane, and this caused complications.

Mr. Gregory said he had not come to give another Paper, but he could say that this three-dimensional lofting equipment had a pretty general application. It was illustrated on what they termed the wallpaper type of jig, but it could be used on the three-dimensional layout of machined fittings. He would not so use it because he thought that to layout a three-dimensional job of that sort by mechanical means was the wrong way round. He thought it should be done by programming.

Mr. Chambers drew attention to the vertical hydraulic copy tracer to provide three-dimensional routing, illustrated in Fig. 7. How far had that development reached a state of perfection ?

Mr. Burnard replied that the machine had been received from Wadkin Ltd. recently. Designed by Vickers-Armstrongs (Aircraft) Ltd., it could produce a component in three dimensions. If they looked at the illustration, they would see that the three-dimensional pattern was mounted on an overhead carrier. A horizontal template was mounted around the component in order to limit the total movement that the operator could get by moving the head, and so prevent him from running off the pattern. The pattern could be made in plastic or it could even be a master component. A hydraulic servo device, made by the Hayes Company of Leeds, operated a double slideway system, giving copying on the work surface. This machine worked quite well and he thought that a number of such machines would be produced in the future. So far as he knew, this was the first installation in this country using a router to get three-dimensional control.

Mr. J. Purcell, A.M.I.Prod.E. (*Research and Development Engineer, The College of Aeronautics*), said that observation had related the destruction of the cutting edge, in machining titanium alloys, to galling of the titanium metal on the carbide or other cutting tool surface. When this was removed, presumably by welding to the component material, a large piece of the cutting edge was carried away. They had found from observation that if they began with a fairly slow surface speed, they could later put the speed up to five times that they would normally get if they began with a constant cutter speed. If they began at 50 ft./min., they could increase by stages until they were cutting at 500 ft./min. This gave reasonable life. The edge seemed to protect itself against damage once this galling had occurred, whereas if they began with a constant speed of, say, 100 ft./min. this protection had not been completed before some part of it was welded to the base metal, and the cutting edge was broken away.

Mr. Burnard suggested that the idea of using chemical lubrication was to prevent pressure welding and the consequent tearing away and cratering of the tool surface.

Mr. Purcell replied that it was difficult to maintain an intermediary between the interface and the chip. To a certain extent it occurred, small impressions being formed which could trap molybdenum disulphide or some other intermediary between the chip and the tool interface. This lasted a certain length of time, but it was not quite as effective as allowing the tool to protect itself and then increasing the speed to operate at five times the starting speed. They had tried to stop this galling from occurring on milling cutters by allowing the tools to pass through a piece of mild steel, a plate clamped to the top of the workpiece; it cut titanium and then passed through the mild steel which removed the galling. This gave better tool life but not as good as when the tool was allowed to protect itself.

Air Vice-Marshal G. R. C. Spencer, C.B., C.B.E. (*Representative, Wm. Jessop and Sons Ltd.*), said that when titanium was machined by people used to it there was no trouble; it was when it was machined by people not used to titanium that there was liable to be trouble.

Mr. Hollis said he had recently visited Jessop's and seen some of their titanium machining, which displayed all the best concepts. For instance, the nose radius of the tool was of considerable importance in tool life, and they were using a 1 in. nose radius in turning a billet. This was a very good practice.

Mr. Taylor commented that the forgings of which he had spoken had not been forged by Jessop's.

Mr. Purcell said the technique of a fine radius for these tools was easily explained. If they had a straight cutting edge and it was followed by a nose radius, the chip on the nose radius was doing all kinds of horrible things to try to flow in the direction in which it would normally go when there was no straight portion. It seemed that with the normal lathe cutting tool the dominating section of the chip was up the straight of the cutting edge ; this dominated the situation and therefore the part of the chip on the nose radius was made to flow in a similar direction, to the stronger straight portion and had to be turned on the interface, which promoted this exactive work on the most vulnerable part of the tool. In using a tool which consisted of all nose radius, the deviation did not occur, hence the chip was allowed to flow naturally, therefore, the protection was continually there (see sketch below).

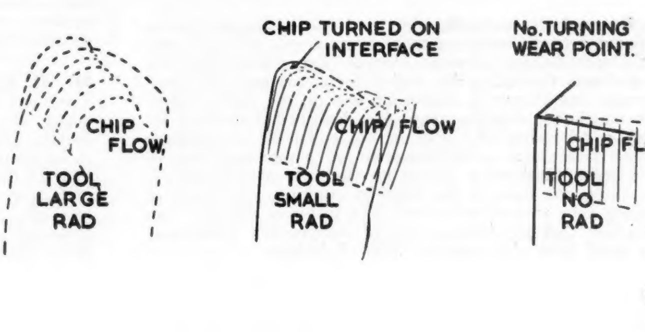
The **Chairman** said the moral seemed to be to use a 1 in. radius.

Mr. Taylor said his experience suggested that they should not let the nose radius of the tool lead the cut. They should apply a negative rake to the top edge of the tool relieved by positive rake, giving a shaving and shearing effect. How often in machining components could a 1 in. radius be used ?

Mr. L. J. Bolton (*Production Superintendent (Hydraulics), Sperry Gyroscope Co. Ltd.*) said they were milling radial slots of $\frac{1}{16}$ in. width with a cam form at the bottom going to a depth of $\frac{3}{8}$ in. or slightly more. They were using a solid carbide cutter of the router type and speeds up to 30,000 r.p.m. An interesting point which matched Mr. Burnard's remarks about vapour lubrication was that, of all known lubricants on the market, they had found that DTD 585 hydraulic fluid gave a better result than any of the proprietary brands. Had anyone else had that experience ? They had increased life up to 50% to 60%. Would anyone from the oil companies like to make a comment ?

SKETCH TO SHOW CHIP FLOW CHARACTERISTICS

(See remarks by Mr. Purcell, above)



(In a written contribution, **Mr. V. G. J. Haden,** A.M.I.Prod.E. (*Lubricants Department, Shell-Mex & B.P. Ltd.*), says: It was stated by Mr. Bolton that his Company was using mist lubrication on routing and milling of light alloys. He mentioned that the lubricant used in this system was DTD 585, which is an hydraulic oil. On looking at the specification, I find that this is a light mineral oil containing an oxidation inhibitor and .5% of tricresylic phosphate. This latter additive would provide some extreme pressure properties and account for the successful application of this grade. On the other hand, one would have thought that a less expensive lubricant, specifically designed for the job, would have given equal results at lower cost.)

Mr. Hollis suggested that DTD 585 was basically a kerosene. In experiments at Cambridge, Dr. Bowden had used for most of the work on fatty acids a suspension in paraffin or kerosene and had obtained very low coefficients of friction. It was likely that DTD 585 had similar anti-friction characteristic and inhibitors.

Mr. Bolton replied that the cutting fluids of many of the oil companies were kerosene based, but they were not a patch on DTD 585. The material he was machining was a steel forging of 65 tons tensile.

Mr. K. Teale, M.I.Prod.E. (*Chief Efficiency Engineer, Short Bros. and Harland Ltd.*), asked for further details of the type of bearings used in the Fairey three-dimensional equipment, hydrostatic or roller type.

Mr. Burnard replied that there were three types of Fairey bearing. The one used in the numerically controlled machine was that in which the cutting spindle was supported on an oil film in which pressure was built up by rotation, forcing the oil into a wedge.

Mr. S. G. Nash, M.I.Prod.E., A.F.R.Ae.S. (*Chief Development Engineer, Bristol Aircraft Ltd.*) said that one small problem in aircraft control tubes which had bedevilled production engineers longer than any other, was getting a precise fit between an internal or external socket tube end and the tube itself. It was the nature of the manufacture of the tube, with its ovality, thickness variation round the circumference, etc., that compelled undesirably large tolerances on the machined socket. He wondered why more had not been heard about chemical erosion in its application to tubes, with a simple method of masking the ends on the internal or external diameter subsequently to be machined. It would then be a simple matter to machine this diameter to really close tolerances to achieve a first-class fit. As push-pull or torque loads were transmitted by pins or bolts joining tube and socket, the static strength or fatigue criteria were provided by these end attachments and it should certainly be possible to save considerable weight by reducing the thickness over the main length of the tube away from the ends by chemical erosion, on the inside or outside as appropriate.

He thought there was an omission from the Paper about the use of spark treatment on high steel tools. He was fishing for information and hoping that someone could explain the mechanism of the process; was it deposition from tungsten carbide electrode, or alloying, or softening? As far as he knew, the metallurgists had not satisfied themselves about this — was there any further information?

Mr. Burnard, dealing with tubes, said that push-pull systems on flying controls were not quite so numerous today, owing to the introduction of servo systems. Tubes were sized by being drawn through a die, and if there was any difference in gauge, the change in dimension was on the inside rather than on the outside diameter. He described a method by which a tube could be held in the collet of an ordinary capstan lathe, and a ball mounted on a mandrel held in the capstan head being forced up the tube as it revolved, thus sizing the bore of the tube by swaging. This method of sizing tube worked quite well. The inside of the tube was burnished, and put into a state of compression which was very good from the point of view of fatigue.

Turning to the treatment of cutters by spark erosion, he thought that Bristol representatives would be able to say more about this than he because he had learned of the process from them. A tungsten electrode was used on the front face of the tool. Spark erosion taking place here was said to transfer a certain quantity of tungsten to the cutting face and also remove a small amount of the parent material, producing minute craters. It might be that this cratering assisted in holding lubricant on the interface between the tool and the chip, and again, it might be the deposition of the tungsten on the surface of the tool which produced the beneficial effects. He was not himself sure.

With regard to the weight question, Mr. Burnard said that the Americans were using chemical etching for rocket tubes for weight reduction purposes. They were leaving parts of the tube thick at the ends where they wanted to make attachments, and reducing the gauge in other places. The difficulty with chemical erosion of the inside of a tube was that of getting away the hydrogen gas. One could immerse it vertically so that the hydrogen gas bubbled up through it. It was also difficult to carry out preferential masking of the internal surfaces.

Mr. S. H. Smyth (*Director, Bowyer, Smyth & Partners*) pointed out that in the film of the chemical erosion process, all the pockets were of the same depth. When they had pockets of many different depths, was there difficulty with the masking? Could Mr. Burnard say a word about the gun reaming technique, which he had said had been described elsewhere?

Mr. Burnard, in reply, said that there were people present who knew more about the gun reaming technique than he. There was someone present who had been engaged on developing it and perhaps he might be induced to speak. A number of pockets were of different depths, and where these were entirely separate, varying depths of erosion could be accomplished by progressive de-masking. Certain areas were uncovered and etching carried out to a predetermined depth, and then other areas were uncovered at this point and etching allowed to carry on. Thus differences were produced. Where one pocket ran into another this was not possible and the part had to be re-masked.

The Americans did not use the same maskant. They used a neoprene rubber in a solvent, which was applied by means of dipping to a thickness of about .008 in. This they cut through with a model knife through a template and then peeled off the area to be exposed for etching. It could be seen that by this technique, they could more readily get differences in depth where one pocket ran into another.

Mr. Teale said there was nothing new in the gun reaming technique; they had merely developed an old idea, by having a single carbide cutting edge and two carbide slipper pads placed radially on the reamer. This gave a far quicker cutting medium than the conventional type of reamer. It had been used chiefly on high tensile steel, and they were using speeds up to 2,000 or 3,000 r.p.m. On $1\frac{1}{2}$ in. S.99 they worked at about 600 r.p.m. and .008 in. feed/rev, giving 5 micro inch finish.

Mr. Burnard said the cutting edge had a lead of about .01 in. to .012 in. on the pressure pads. It was a single point tool and it would correct any run-out. The pads themselves had a burnishing effect. They put it in a state of compression, which helped fatigue life. Through the use of this method, there were two or three advantages.

Mr. H. E. Lardge (*Chief Metallurgist, Joseph Lucas* (*Gas Turbines*) *Ltd.*) referring to paragraph 13.1 of the Paper, asked what was the finishing operation used to remove certain machine marks? Secondly, he was a little worried about chemical milling or chemical etching from the point of view of the surface and particularly from the point of view of fatigue. Mr. Burnard had dealt mainly with light alloy, but Mr. Bucey had mentioned the chemical milling or chemical etching of stainless steel. Some years ago he had done some work on electrolytic etching and some fatigue

tests on 18/8 steels and Nimonic 75. The fatigue value was definitely down. Since the importance of fatigue was now appreciated by all, he would appreciate it if both Mr. Burnard and Mr. Bucey would comment on the point.

Mr. Burnard, in reply, said that stress raisers were important mainly where areas of high stress were concerned, that is to say, in radii and highly loaded flanges, etc. Therefore, they took particular care to clean out the radii of a component, and could accept a worse finish in the web. It was possible to carry out normal barrelling techniques and then remove any machine marks still apparent in radii, by hand buffing. Alternatively, the component could be finished by going over it with vapour blasting. Both methods were satisfactory for the reduction of stress raisers.

Regarding fatigue life of chemically eroded light alloy specimens, there might be some hydrogen embrittlement of the surface which could affect the fatigue life. However, an extensive series of tests had been carried out by the Research Department which had satisfied the authorities and all concerned that the fatigue life was not affected. By the post heat treatment method described in the Paper, they got a better fatigue life from chemically eroded parts than from machined parts. From an examination of the scatter on S-N curves, they thought this was because chemical erosion was so much more uniform than machining.

With the chemical erosion of steel there would undoubtedly be more fatigue difficulty and hydrogen embrittlement would be more prominent. The problem of the chemical erosion of steels in this country had not yet been solved. Some erosion of all kinds of steels was being carried out in the United States. However, the depth of pocket eroded was not very great — probably a maximum of $\frac{1}{16}$ in. Mainly, the process was used for missile skins. He did not think that anything was done about fatigue in these cases, as a missile has a very short life and, therefore, the question of fatigue was not relevant. Perhaps Mr. Bucey could say what they did about fatigue.

Mr. Bucey said he could not give the details. All the tests had been conducted by their engineering department. They had been sceptical at first, but the many tests had seemed to prove that fatigue was not a problem with the shallow work they did. Most of the work had been missile work, where fatigue was not a problem ; Boeing were not using it for aircraft parts, although some companies were, for example, at Los Angeles on fighters. He did not know whether these companies had solved their problems.

Mr. Burnard said that there would be a great saving if it were possible to erode high tensile steels chemically. It would be useful if they could use the controlled erosion of steels on roughing out operations. However, one of the results of chemical erosion was the production of a radius in the corner of pockets which was equal to the depth. On deep pockets this resulted in large radii which must afterwards be removed by machining. In this case, fatigue or embrittlement would not be of any consequence, because there would be a final machining operation.

Mr. A. J. C. Smith, A.M.I.Mech.E., A.F.R.Ae.S. (*Development Engineer, The Fairey Aviation Co. Ltd.*), asked whether it was a case that whether chemical etching was used or not depended on the radius that the designer would accept, or were there other restrictions on depth ? Mr. Burnard said he had approval for the process. Was that restricted to certain specifications ?

Mr. Bucey had mentioned large forging presses. He had heard of none in this country. Could we have some very large ones, particularly in view of the development of integral construction ? In the smaller forging presses or drop stampings, would not closer limit forging be an asset — to within 0.1 in. or even better ?

Mr. Burnard replied that in general they went down to depths similar to those in the specimen exhibited, and these radii were acceptable. The maximum depth they were etching at the moment was $\frac{1}{2}$ in., and they had approval for these radii in those cases. The position would be different on depths of, say, 1 in. Such a radius might not be acceptable, but with chemical erosion the surface became progressively worse the deeper the etch, and it would seem that because of this they would have to carry out a finishing operation in any case to remove surface imperfections. The radius could then be corrected. They had Ministry approval for almost all of the alloys. Working the materials in the fully heat treated condition gave the best surface finish. The maximum limit set by the Ministry at the moment was 0.5 in.

The question of large forging presses had been discussed at length at previous Conferences — it did not seem that there would be any likelihood that they should buy one in this country for several reasons. One was that it would require the expenditure of hundreds of thousands of dollars. Another was the high cost of dies to produce close to limit forgings, together with the lead time involved in their manufacture. Since aircraft quantities were small, it would not pay to produce such expensive dies for a very few forgings, and it might be difficult to keep the press going. In close limit forging one would have to use a series of dies in order progressively to bring the forging to the required close tolerances. This would be a very expensive matter for small quantity production.

Mr. Rogers said that it had been found, on the engine side of the British aircraft industry, that there was a significant improvement in the fatigue life of components which had been electrolytically or chemically eroded, if mechanical polishing of the eroded surfaces was carried out after etching. He did not know the extent of the improvement, but by putting a buffing mop over the etched surface, using a suitable polishing compound, a definite improvement was effected, probably due to the restoration of the surface stresses as a result of mechanical working. Whether this improvement was good enough for what was required on the airframe, he did not know.

Mr. R. M. L. Elkan (*The Loewy Engineering Co. Ltd.*) said that he was associated with the firm who had built the heavy stretcher shown in the film which had just been shown. Commenting on Mr. Burnard's remarks, he said that very large presses could most certainly be designed and built in the U.K.; his firm had been associated with the design of the two 12,000 ton die forging presses which had been working in this country for quite a number of years, and the experience on which also served in the development of the design of the heavier units installed in America.

There would appear to be two distinct trends at the moment, one being the combination of stretch levelled plates used together with the very fine machine which they had just seen on the film, a trend which might be best suited to the conditions in Great Britain at this time; and the other consisting of the use of very heavy presses in conjunction with the precision forging technique. Although the latter approach might not at present be considered appropriate for the conditions in this country, the American developments should not be ignored. Four major press units were in operation in that country, two of 50,000 tons capacity and two of 35,000 tons capacity, in addition to a considerable number of presses of somewhat lower powers. All these units were reasonably heavily loaded with work, and some development of the precision forging technique was at present taking place. These alternative developments should not be overlooked, and it would be well also not to lose sight of the possibilities of extrusion and other processes utilising heavy hydraulic presses, not only for light alloys but also for steels and titanium alloys.

The **Chairman** said that in reading the Paper and listening to the discussion he had been reminded of the man who said that all ideas for advancement and betterment must go through three phases. First, when they say it is impossible; secondly, when they say it is contrary to the will of God; and thirdly, when they stand back and say with pride, "I always said it would work". Tonight they had had quite a few of the ideas which work.

On behalf of the Institution, he thanked Mr. Burnard very much for his Paper.

The Conference then adjourned.

three-dimensional tape-controlled inspection

by H. J. Elton, A.M.I.Prod.E.

Engineer I

Inspectorate of Electrical and Mechanical Equipment,

Ministry of Supply.

WITH the advent of tape controlled machine tool systems, which can accurately control the path of a cutting tool in three planes, a new avenue of inspection is available. Very broadly, if a measuring head is substituted for the cutting tool, continuous and automatic inspection of physical dimensions can be undertaken, provided the measuring head is capable of indicating movement in three planes. With this object in view, the Inspectorate of Electrical and Mechanical Equipment, Ministry of Supply, have designed such a measuring head, coupling it to a standard indicator and recorder system. A demonstration of this system was carried out on a Ferranti computer controlled milling machine in June, 1957. Figs. 1 and 2 show the demonstration layout.

In the Ferranti system of machine control, movements of the machine carrying the component are accurately controlled in three planes by 'playing' a magnetic tape into a control unit. (A detailed description of the Ferranti system is not included in this report.) Thus it is possible to programme the path of a component such that the surface to be measured is in contact with the stylus of the measuring head. Any difference in shape from the true programmed path will cause a movement of the stylus which is indicated and/or recorded.

The measuring head (Fig. 3) is designed to fit into the machine quill and carries at its opposite end a ball stylus which contacts the surface of the component under inspection.

When checking or contacting a vertical face, the stylus moves in a horizontal plane, swinging about the ball seating, imparting a vertical movement to the outer sleeve which carries a bar to contact the end of an inductance type sensing element. This is directly connected to an indicator and recorder. Thus, if the dimensions A and B are 1 : 1, a horizontal movement of the stylus of say .010 in. lifts the outer sleeve exactly the same amount with the indicator and recorder reading .010 in.

Similarly, when checking a horizontal face of a component, the stylus moves in a vertical direction (the ball joint moving vertically in its seating), again imparting a vertical movement to the outer sleeve as before.

Investigations are proceeding on the use of the head on faces at any angle.

indicator and recorder system

The mechanical movement of the end of the sensing element causes minute electrical changes, which are transmitted through an amplifier unit, to an indicator calibrated in units of .001 in. This is coupled to a recorder and limit light signals which can be set to the desired tolerance. The light signals and recorder may be used individually or simultaneously.

The sensing element, and indicator (including the amplifier) and light signals are standard equipment manufactured by Southern Instruments Ltd.

test piece

The component for inspection was a test piece (Fig. 4) designed for the demonstration to include the following features for inspection :-

1. hole positions and diameter ;
2. position and angle of a 45° vertical face ;
3. depth, width and position of a slot.

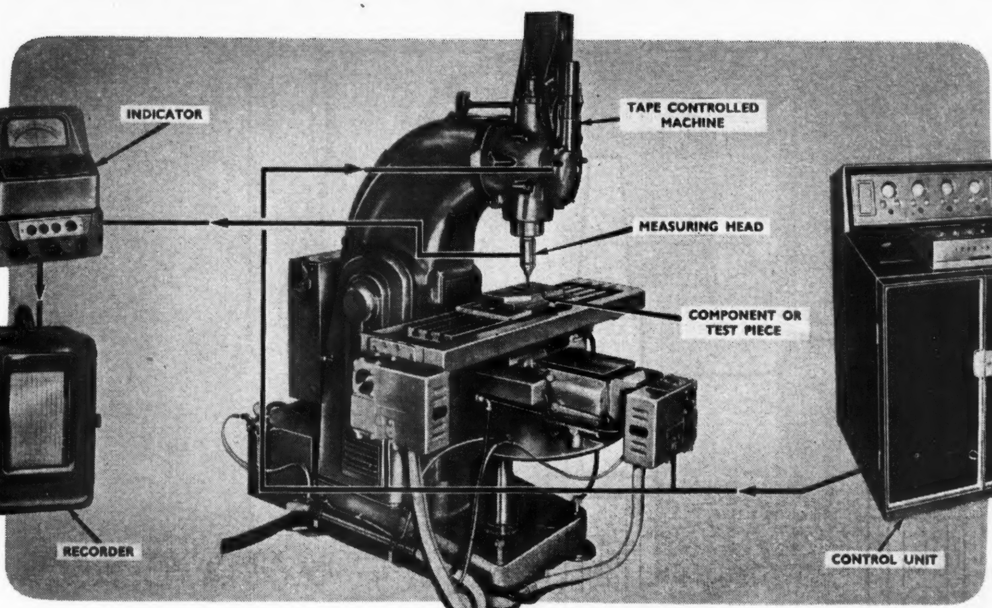

INDICATOR
TAPE CONTROLLED MACHINE
MEASURING HEAD
COMPONENT OR TEST PIECE
RECORDER
CONTROL UNIT

Fig. 1

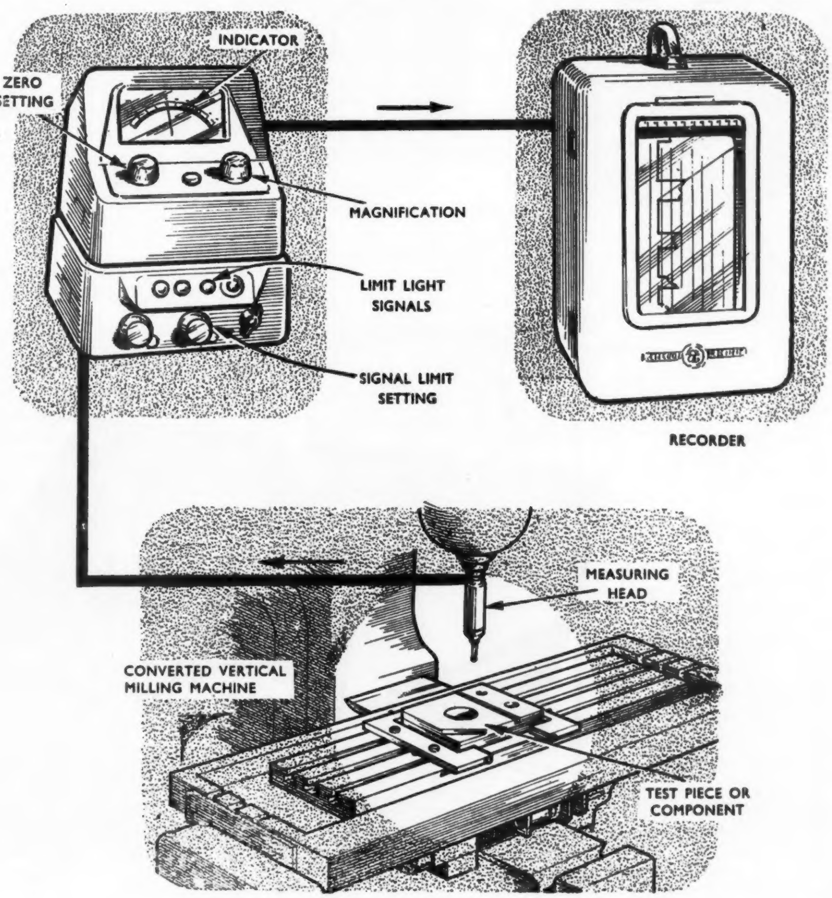

INDICATOR
ZERO SETTING
MAGNIFICATION
LIMIT LIGHT SIGNALS
SIGNAL LIMIT SETTING
RECORDER
MEASURING HEAD
CONVERTED VERTICAL MILLING MACHINE
TEST PIECE OR COMPONENT

Fig. 2

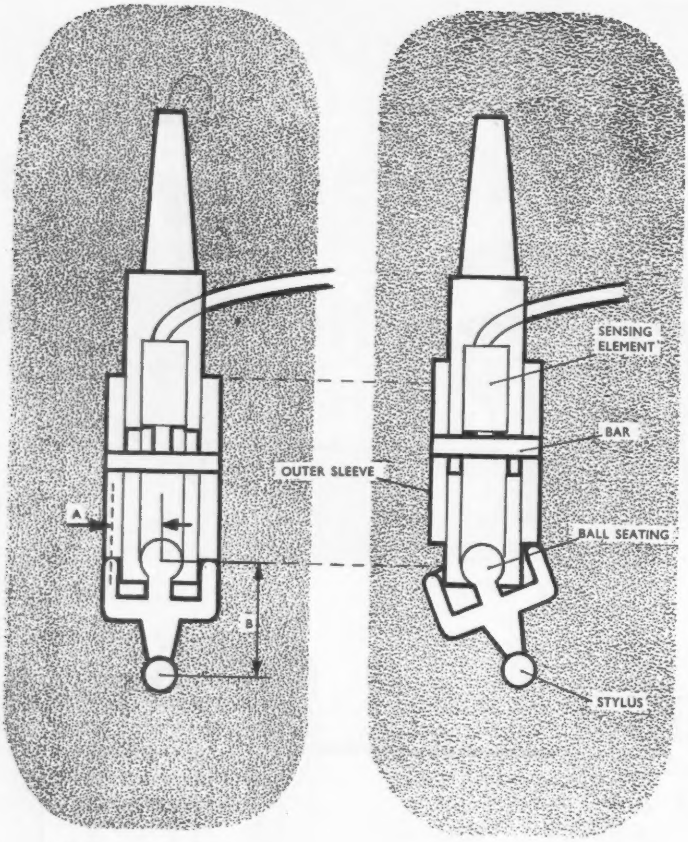

SENSING ELEMENT
BAR
OUTER SLEEVE
A
BALL SEATING
B
STYLUS

Fig. 3

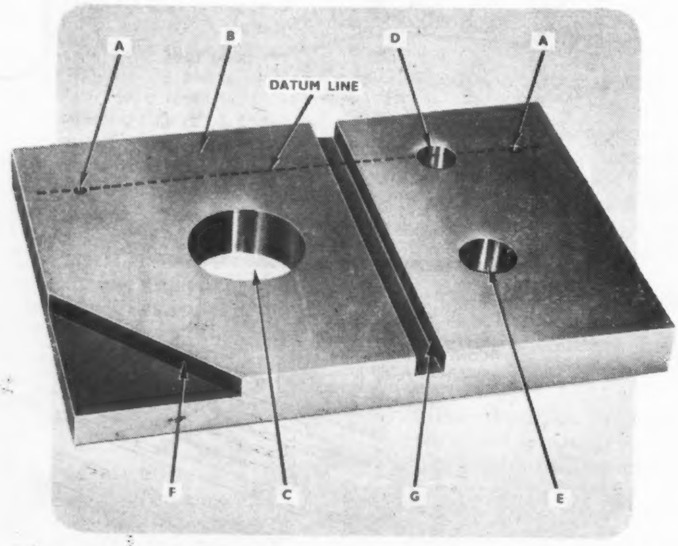
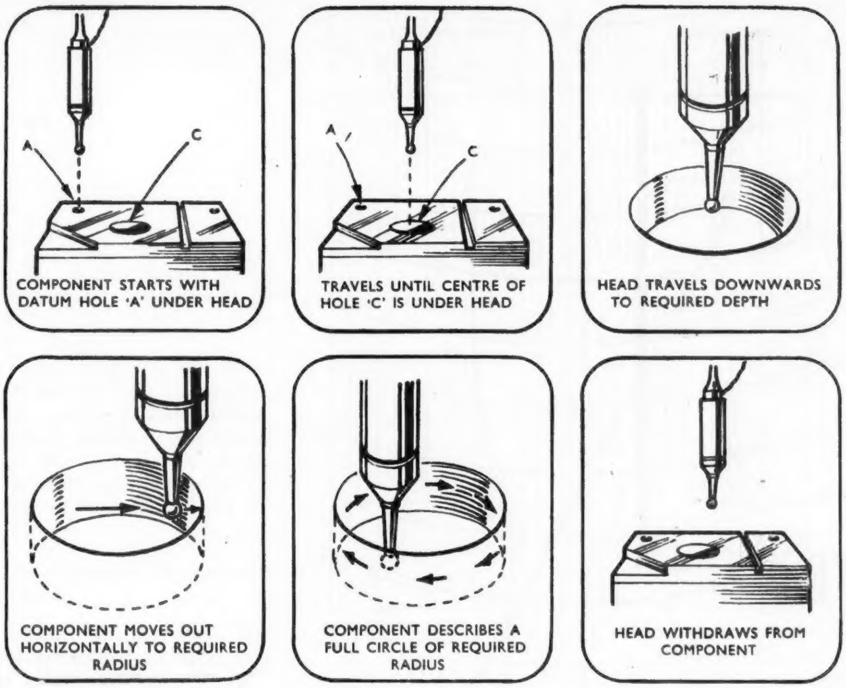

A
B
D
A
DATUM LINE
F
C
G
E

Fig. 4

Fig. 5



These features were related to two datum holes A and the top face B, the machine being initially set relative to these datums. Provision can be made in the programming to check from any datum feature.

programming and operation

Having decided the surfaces to be checked and the sequence in which they are to be measured, a planning sheet can be prepared from a conventional drawing dimensioned from the three datum planes. This information is typed into a perforated tape, which when played into the computer produces the magnetised tape. Having physically set the machine on its starting datum, the machine table carrying the 'component' is sent on its programmed course by playing the magnetic tape into the control unit. Referring to Fig. 5, it can be seen that the machine starting with Datum A under the head, carries out the following movements :-

1. travels until the centre of hole C is under the head ;
2. head travels vertically downwards to put stylus ball at the depth where position of hole is to be measured ;
3. moves horizontally a distance equal to radius of hole minus stylus ball radius, plus a pre-loading figure of say .01 in. (this is added during planning in order to obtain a deflection of the stylus for a hole which is over nominal size and/or out of position) ;

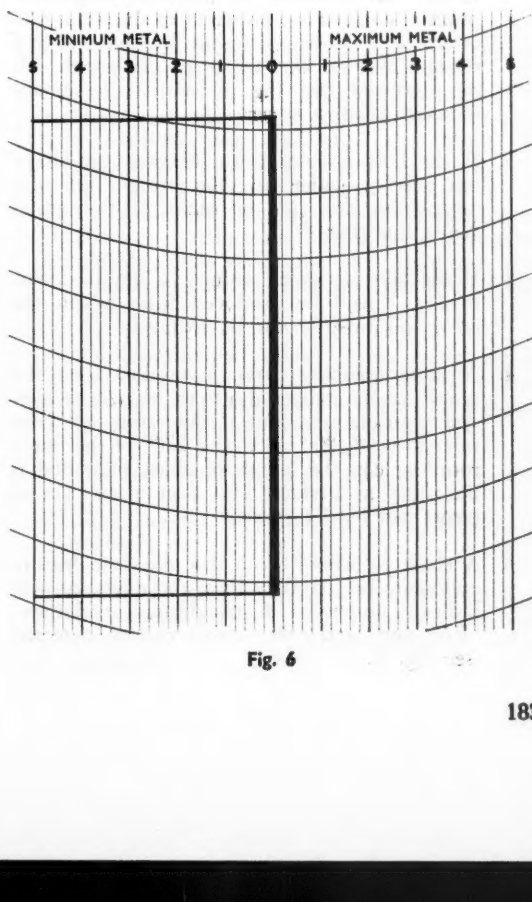


Fig. 6

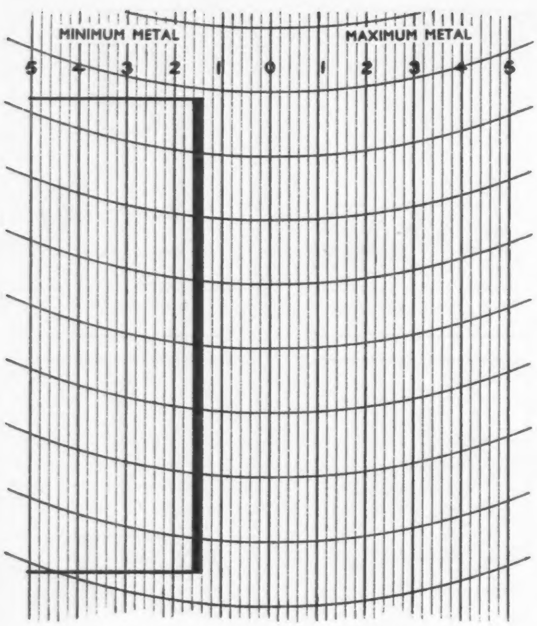
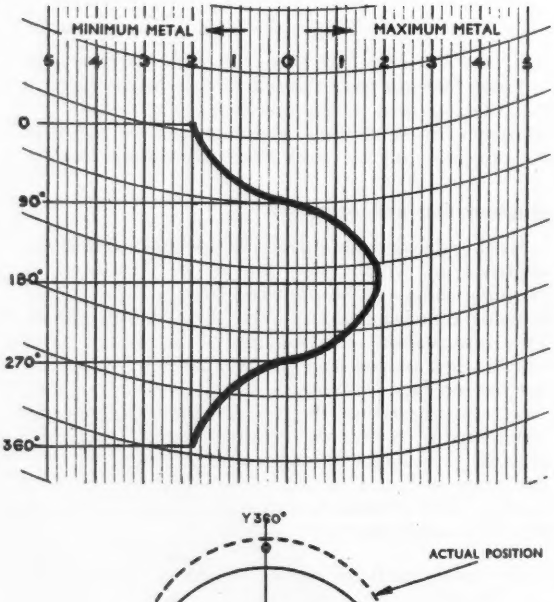
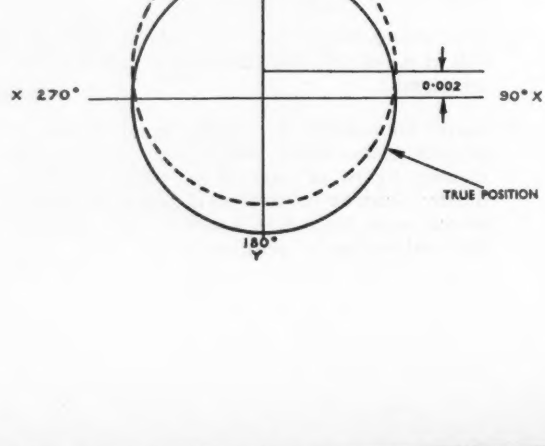


Fig. 7 (left)

Fig. 8 (below)





4. the component now moves horizontally in a planetary motion describing a circle of radius equal to horizontal movement — see 3, above.

indicated and recorded results

1. If the hole is correct for diameter, shape and position no further movement of the stylus will occur as it traverses round the hole and a straight line on the centre of the graph will be produced (see Fig. 6) with a stationary indicator reading at zero.

2. If the hole is correct for position and shape but over or under size, the straight line will appear on one side or other of the graph centre line (Fig. 7).

3. If the hole is out of position, a graph similar to Fig. 8 will be produced from which the error and direction can be deduced.

4. A more complex curve is produced on the graph when combined errors of size, ovality and position exist, but if the errors are considered at 0°, 90°, 180° and 270° of the hole's rotation, e.g. the length of chart recording is imagined as divided into four parts, actual errors can be determined.

5. A chart recording for a true flat face feature will again be a straight line; and deviation will indicate an error of straightness or flatness. 'Run out' and other errors can be detected (see Fig. 9).

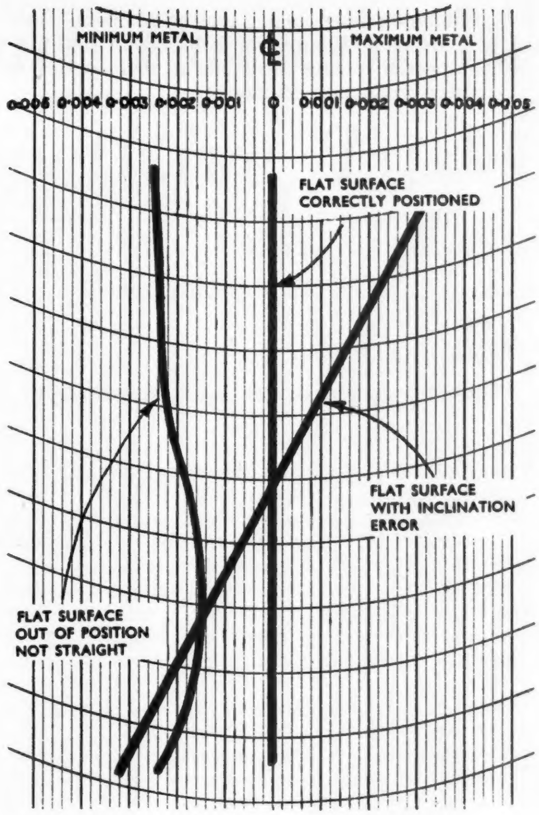


Fig. 9

6. Errors in any profile are in fact shown up as deviations from a straight line graph and its position on the chart.

7. The path chosen for inspecting the test piece (Fig. 4) was Datum A to hole C and traverse, to hole D and traverse, to hole E and traverse, to 45° face F and traverse, to side of slot G and traverse, traverse back along other side of slot G, to top surface at slot G (height) to bottom of slot, along bottom of slot and back to datum A.

Fig. 10 shows the type of graph which was produced from the test piece, Fig. 4.

The chart speed chosen was 6 in. per min. The component or test piece was controlled to move at a constant speed of 9 in. per min.

The playing time for the inspection of this test piece was 13 minutes.

proving head

As a precautionary measure, a dummy measuring head with a flexible stylus is used in the first instance to prove that excessive errors are not present. This can be set to illuminate a warning light at any given accepted figure, and obviates damage to the measuring head with its limited movement.

conclusion and general remarks

The results from this demonstration were very encouraging. On successive runs results were repeated within .0006 in. Accuracy of results was within .002 in. It must be appreciated that these figures were obtained on an ordinary production milling machine.

With the aim of improving on these figures, I.E.M.E. are proceeding to convert a jig boring type of machine into an inspection machine using the principles described. At the same time the design of a final inspection machine is being undertaken.

Within the capacity of the machine any component can be dimensionally inspected, whether it be manufactured by computer controlled machine tools or not. Gauges and fixtures can also be inspected.

Some of the advantages to be considered are :-

1. speed of inspection ;

2. storage of tapes makes for ease in repeated inspection at intervals ;

3. the inspection machine could check a variety of components one after the other simply by playing different tapes into it ;

4. the inspection machine could be installed to check the production of a number of controlled machine tools producing at a high rate, production in batches being released after sample inspection ;

5. the 'continuous' aspect of the system is far more comprehensive than any normal inspection method. The surface at a hole for instance is not normally checked throughout 360° ;

6. graphed results easily recorded for reference ;

7. time saving in preparation of dimensional reports ;

8. copies of tapes supplied to manufacturing centres make standardised inspection methods possible, which can be extended to other countries ;

9. eliminates design manufacture and maintenance of expensive gauges, and inspection staff ;
10. inspection media available at short notice to meet production demands ;
11. modifications can be incorporated during production simply by supplying a new tape, as opposed to time taken to alter gauges.

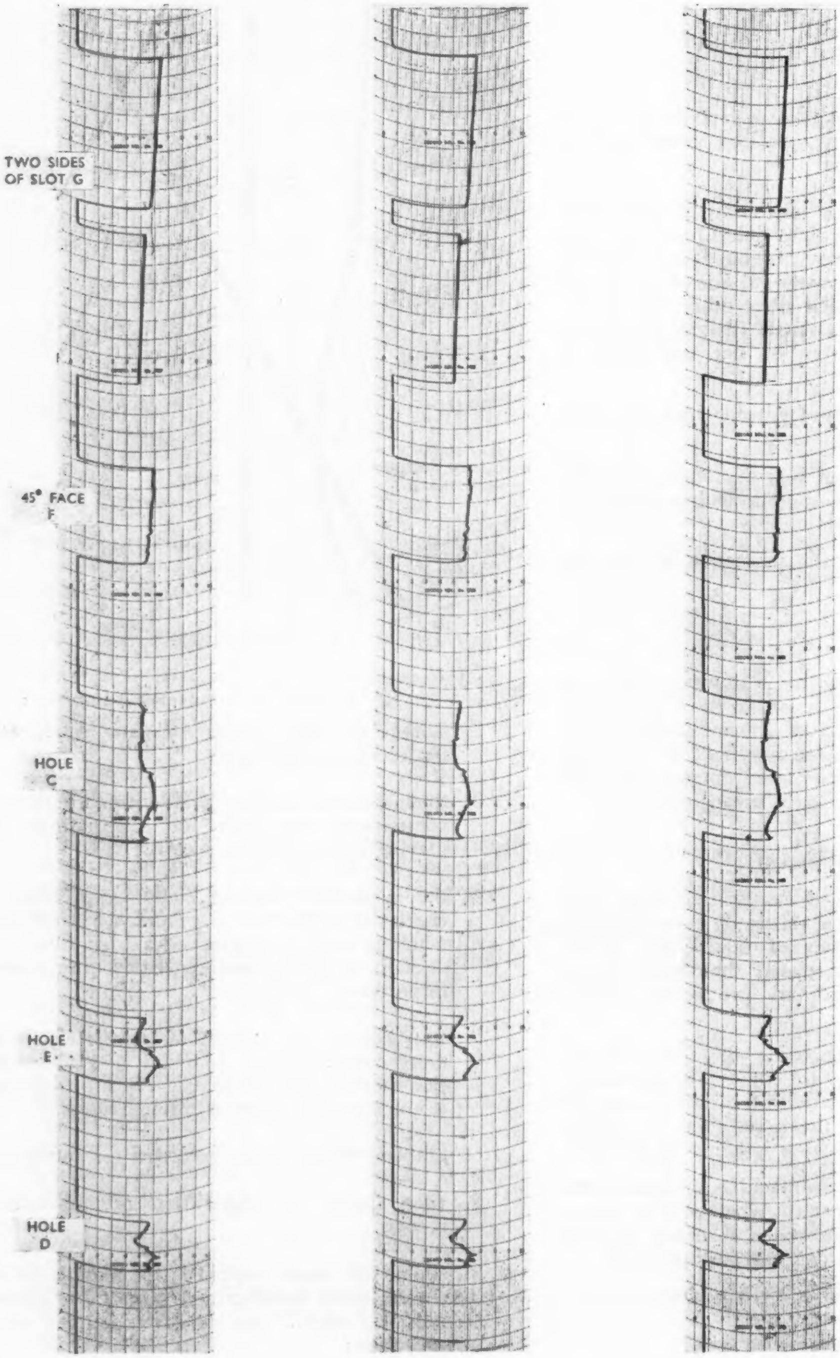


Fig. 10

Acknowledgements are made to Messrs. Ferranti Ltd., Edinburgh, for their co-operation and assistance in carrying out the tests.

The equipment and system described in this Paper are the subject of provisional patent applications.

Output Pattern in Repetitive Tasks

with special reference to Compensating Relaxation Allowances

by N. A. DUDLEY,
Ph.D.(Birmingham), B.Sc.(London), M.I.Prod.E.

Dr. Dudley is Reader and Head of the postgraduate Department of Engineering Production in the University of Birmingham. He is also Director of the University's Residential Institute for Engineering Production.

Before joining the University in 1952, Dr. Dudley held a number of technical college appointments, including the Senior Lectureship in the Department of Engineering Production at Wolverhampton, following some 14 years' production engineering experience in industry. He has recently planned the first M.Sc. Degree Course in Operational Research in the United Kingdom.

THIS is a summary of a research thesis [1] based on a three year investigation begun in May, 1952. Although this research and its implications have been discussed in numerous lectures given in the University of Birmingham Institute for Engineering Production and in a brief interim report [2], the detailed research findings have not hitherto been published. References [3] to this work, however, and the adoption of its recommendations by a number of industrial companies have encouraged the author to prepare this account, which is to be published in consecutive issues of the Journal in four parts, commencing with the present issue.

The primary purpose of the research was to contribute to the establishment of a scientific basis for the allocation of "compensating relaxation" allowances in time study practice, the nature and development of which are discussed by way of introduction.

PART I

background and formulation of hypotheses

time study

Time study is one of several techniques of work measurement which are used to establish performance standards, in terms of time or work unit value, for purposes of production planning and control, the estimating of labour requirements and production costs, the determination of standard costs, and as a basis for remuneration.

The use of this technique is appropriate for the study of manual operations which are sufficiently repetitive to have justified standardising the methods of working and the layout of the materials and equipment used, and training the workers in their performance.

The basic assumption of time study, as commonly practised, is that variations in the time taken by a trained and experienced worker, performing an operation in a standard manner, are to be attributed to :-

1. voluntary changes in the operator's pace of working ; and
2. involuntary relaxation of effort due to diminishing capacity for work, manifesting itself in a decreasing working pace and the occurrence of pauses as the work proceeds.

Time study procedure seeks to compensate for the first of these influences, by "rating" the operator's working pace and, for the second, by the award of "compensating relaxation" allowances.

time study rating

The time study procedure most widely adopted is as follows. The operation cycle is first divided into clearly defined work elements, suitable for observation and timing. The time study observer then records the times actually taken to perform the sequence of elements, over a number of complete cycles, until a sufficiently representative sample of the work involved in the operation has been obtained.

During the observation of the operation element, and immediately prior to recording the element time, it is customary, in British practice, to record the "rating" of the operator's working pace. This rating is a subjective assessment, expressed numerically, of the actual pace relative to the observer's concept of the "normal pace" for the operation. The product of the actual element time and the rating

factor is the "normal time", or the time which the operator would take to perform the operation when working at normal pace.

An investigation of time study rating practice in the United Kingdom was undertaken during 1950-1951 by the University of Birmingham Work Measurement Research Unit, under the direction of Professor T. U. Matthew, then Head of the Department of Engineering Production. Reference in this present Paper will be made to the interim, unpublished, report [4] on this research entitled "Accuracy of Rating in Time Study", and to the doctorate thesis of C. J. Anson [5], entitled "The Quality of Time Study Rating", which is based on the pilot survey, made by the Unit.

Reference is also made to the report on a similar national research project conducted in the U.S.A. by the Society for Advancement of Management in co-operation with the College of Engineering, New York University [6]. Details of another, but smaller-scale, investigation sponsored by the Nuffield Foundation, and directed by Mr. Winston Rodgers have also been published [7].

compensating relaxation allowances

To the normal time of each operation, or preferably to each element, is added, usually as a percentage, a compensating relaxation (C.R.) allowance, the magnitude of which is dependent upon an assessment of the fatiguing effect of the work and of the conditions under which it is performed.

Thus the Standard Time (or Work Unit value) of an operation =

Σ (Normal Time + % C.R.) or, in some companies,
Σ (Normal Time) + % C.R.

The small allowance of time required by workers for attention to personal needs is customarily included in the C.R. allowances and comprises some 2½% to 8%.

origin of C.R. allowances

"Elementary Time Study" was first developed by F. W. Taylor (1895) [8], who multiplied the sum of the average element times "by a factor which allows for rest and other necessary delays" [9].

In one of his early experiments Taylor determined the optimum ratio of work and rest for labourers loading pig iron on to railway waggons. Each pig weighed 92 lb., and a gang of men were employed to pick up a pig from a stack in a field, to walk 36 ft., then up an inclined plank and to drop the pig into the waggon. When Taylor started his studies, the gang of 75 men were loading an average of 12½ tons of pig iron per day per man. After Taylor had experimented, he found that a first-class labourer, suited to handling pig iron, could be under load only 42% of the day, and that with suitably arranged rest pauses, each man should be able to handle 47½ tons per day.

In practice, out of the 75, only eight were found who could and did maintain this output on incentive, and these men were carefully trained to take rests by sitting down after loading 10 to 20 pigs. There was considerable interest in experimental studies of this type 40 to 50 years ago, and there is in existence a film made by Frank B. Gilbreth, the motion study pioneer, of this particular experiment [10].

A study of the data accumulated during these early experiments led to the development of a number of empirical "laws of effort". An example of these is Taylor's "Law of Heavy Labouring" — "... for each given push or pull on a man's arm it is possible for the worker to be under load only for a definite percentage of the day".

D. V. Merrick (1919) [11] recommended that the operator studied should be a first-class worker, and that fatigue and other allowances added to the measured times should be such as to bring the resulting rates within the range of ability of the average worker.

Charles E. Bedaux developed the Bedaux method of time study, in which the observer rates each element for speed and effort and awards an appropriate C.R. allowance. Much has been written on the Bedaux system, described by G. Schlesinger (1930) [12], and its comprehensive tables of C.R., but little information has actually been revealed regarding the values, and less concerning the means by which they were derived.

It is claimed in an International Bedaux Company advertising publication of 1932, that Bedaux established a concept of the unit of work about 1916, while Morrow (1922) [13] records a set of laws relating to the strains which occur during working, formulated by Bedaux about 1911. Bedaux's principal "Laws of Effort" are as follows:-

"for muscular effort of a given power:

1. the ratio of strain to effort is directly proportional to the rapidity of the motion and to the length of the work cycle;
2. the duration of work and rest period is inversely proportional to the rapidity of the motion and the length of the work cycle."

Morrow observes that it was by using these laws during the five years 1911-1916 that Bedaux established relaxation allowances for different tasks, allowances which vary from 15 to 210% of the working time.

P. K. Standing (1934) [14] states that "the approximate relaxation allowance for all tasks is obtained from tables which have been calculated by Bedaux experts".

An article by the Italian Ministry of Companies (1934) [15] claims that, because of the specially prepared tables "in the Bedaux system, the subjective estimation is limited to judging the speed of working which is relatively easy to those with the necessary experience".

Stroobant (1939) [16] says Bedaux made a long investigation into the question of relaxation, and that his experimental results were used to establish laws for determining the rest allowance to be given in each particular case. The range of allowances established was from 8% - 250%.

In "Le Système Bedaux" (1936) [17] the management of the Society Compans claim that the relaxation allowances necessary for different

elementary movements were determined by measuring the amount of CO_2 and lactic acid produced by the physiological reactions of the subjects under observation. Further, that numerous measures taken in physiological laboratories were interpreted in the form of graphs and tables which the Bedaux engineers used to determine the rest allowance for any particular task.

Wackwitz (1936) [17] confirms this statement and added that Bedaux had determined the rest factors experimentally at a physiological institution in New York. Schlesinger (1930) [12], however, asserts that the values were established after several years of working in diverse industries, together with the results of physiological experiments.

It is of interest to note that whereas Taylor insisted upon planned and controlled periods of rest, the Bedaux Company "urge emphatically that these (allowances) are incorporated with the firm intention that advantage should be taken of them . . . but . . . the manner of taking the rest allowances must generally be left to the workers and employers concerned" [18].

current theory

Most books on the subject of time study are of U.S.A. origin and follow closely on the pioneer work of Bedaux, insofar as they retain his conception of the relation of work and fatigue.

W. G. Holmes [19] adopts an entirely mechanistic explanation of fatigue, and gives complicated data of allowances based on consumption of energy for various primary movements operating under various conditions of strain. He, in common with several other writers, claims that the published figures for fatigue allowances are based on "many studies made in an endeavour to determine the relation between strain and the various degrees of energy expended for each type of motion in the performance of a job, so that ratios thus ascertained could uniformly be applied to all work done by man". None of these authors give in full these many studies and experiments but merely quote the results which, unfortunately, vary considerably.

Lowry, Maynard and Stegemerten [20] observe: "The question of fatigue has caused considerable discussion, and there have been various theories and ideas advanced concerning ways of counteracting the effect of fatigue on the worker. Extensive experiments have been conducted to determine the effect that rest periods have on fatigue. Some interesting results have been obtained from these experiments, but the results and claims are not consistent. This inconsistency is believed to be due to the human element. It is believed that a fair fatigue allowance should be determined and added to each job to be used at the discretion of the operator". These authors recommend that "a number of individual workers are studied for a week or two, or even longer, depending on the variableness of the work", rather than that allowances should "be estimated or decided in an arbitrary manner".

Professor F. L. Meyenberg [21], formerly Secretary of the Reichsausschuss fur Arbeitszeitermittlung (R.E.F.A.), questions the need for C.R. allowances, and stresses that the methods of allowing for fatigue are arbitrary, adding: "It is certainly better to be fully aware of this state of affairs and to act accordingly than — as some experts do, deceiving themselves, or others — to claim to have found out the correct answers and to build up on them a quasi-scientific system to be used as a panacea".

Professor R. M. Barnes [22] writes "The problem of determining the amount of time to be allowed for rest is very complex. Time needed for rest varies with the individual, with the length of the interval in the cycle during which the person is under load, with the conditions under which the work is done, and with many other factors, Some companies have from long experience arrived at fatigue allowances which seem to be satisfactory". And Professor Barnes publishes a list of personal and fatigue allowances used by one company as an example.

Ralph Presgrave [23], writing on the fatigue allowance, says: "... this is almost invariably the main allowance in any study", but adds: "what little knowledge we have as to the causes, nature, and effect of fatigue serves only to illuminate our vast ignorance".

current practice

Many industrial companies have established C.R. allowances which appear to be satisfactory in the sense that, although often challenged, they are acceptable to managements and workers in principle, and appear to be a necessary component of standard times and work unit values in practice.

The factors usually considered, and for which a graduated time allowance is made in each case, include :-

- physical effort (equivalent weight) ;
- working position (sitting, standing, stooping, kneeling, etc.) ;
- working movement (walking, or restricted in location) ;
- lighting conditions (as affecting difficulty of observation) ;
- concentration required (eye attention) ;
- air conditions (ventilation, temperature, pressure, humidity) ;
- special clothing (protective, etc., causing discomfort or obstruction) ;
- noise level ;
- personal needs.

Conflicting theory, inadequate research and lack of uniformity in practice tend to support the view that there is little or no scientific basis for the allowances actually given in practice. Indeed, many of the figures have been arrived at by intelligent guesswork and subjective estimation.

In recent years, a few companies have endeavoured to rationalise their C.R. allowances, with the result that certain anomalies have been removed. The general lack of uniformity in practice remains.

For this reason, research findings which may have some bearing on this problem are being critically

examined, while a number of research projects have been and are being undertaken with the specific objective of providing data relating to the need for C.R. The primary purpose of the research which forms the subject of this present thesis was to contribute to the establishment of a scientific basis for the allocation of C.R. allowances.

measurement of fatigue

The pioneer work on fatigue measurement was done by A. Mosso, author of "Fatigue" (1890) [24] who invented the ergograph apparatus to record the work done by a few muscles of the body. Dr. May Smith [25] describes one of several forms of this instrument and refers to the results that "have been achieved relating to the fall in efficiency after a time, the advantage of rest pauses, and the disproportionate time for recovery". She also observes, however, with reference to the ergograph experiments, that "there was the question of how fatigued the subject was" and that "the fatigue was probably local".

Professor William McDougall (1905) [26] advanced the view that well-fixed habits or simple tasks were useless as measuring rods except in extreme cases of fatigue, and that a process late in development and more sensitive to change should be selected. He consequently devised a test "to provide the subject with a task demanding for its execution a continued maximal voluntary concentration of attention". The apparatus, which has been widely used, is described by Dr. Smith (1916) [27].

A modified and portable version of this apparatus known as Dr. Schuster's "disc-dotting machine" has been used in some industrial experiments.

A weakness of such psycho-motor tests is that the novelty of doing the test tends to mask the fatiguing effects of the activity on which the subject has been engaged.

Physiological aspects of fatigue have been studied[28] in considerable detail, observations being made of changes in oxygen consumption, pulse rate, blood pressure, waste products in the blood, body temperature and body weight, and metabolic cost.

Experiments are now being carried out by T. A. Ryan [29] in the measurement of mental and skilled manual work by amplifying the electrical changes in the muscles and on electrical resistance of the skin.

The Max-Planck-Institut fur Arbeitsphysiologie at Dortmund has produced two important portable instruments [30]. The first is a breathing-gas clock which can be carried on the back to measure calory consumption through the consumption and production of CO_2. The second is a pulse-measuring apparatus also carried on the back which, it is claimed, is of use when attempting to discover whether the reason for falling productivity is due to fatigue or to other, psychological, causes. Other investigations that are being carried out at Dortmund include the effects of lack of sleep, of vibration, such as that of pneumatic equipment, and the influence of temperature and nutrition on productivity [31–32].

Experimental work in this field is being carried out by the Medical Research Council Unit for Research in Applied Psychology at Cambridge [33], at the Oxford Physiological Laboratory, by the French Bureau d' Etude et d'Organization du Travail [34], and the Industrial Hygiene Foundation of Pittsburg.

Measurement of pulse rate has been found to be a particularly reliable gauge of fatigue. The Harvard Fatigue Test consists of counting the pulse rate at one minute intervals during the first three minutes of the recovery period, and from such tests two conclusions have been drawn :-

1. the heavier the work, the higher the heart rate, and the slower it comes back to resting level ;
2. the better the physical condition of the individual, the smaller the increase in heart rate, and the more rapid the return to resting value [35].

Further examples of "Physiological Measurements in Work Study" have been reviewed by J. A. C. Williams (1955) [36], while recent research findings on "Fatigue" published by the Ergonomics Research Society [37] include work which has a direct bearing on this subject.

Valuable though the results of such physiological and psychological laboratory experiments are in providing data regarding the onset of and recovery from fatigue, they cannot be considered as directly applicable under industrial working conditions in practice, and are generally of such a nature that their repetition under these conditions is impossible. The tests which yield the most consistent results are, at most, fragmentary, relating to individual factors. Moreover, a series of tests would not be wholly satisfactory, since it is not the aggregation of the individual effects of individual fatigue factors that is being sought but, as Professor Barnes [38] states, the combined effect on worker performance of a complexity of interacting fatigue factors. Indeed, as D. C. Fraser [39] writes: "When we turn to the consideration of the whole organism, the physiological picture becomes less clear. It is possible to demonstrate that waste products of muscular activity accumulate where there has been excessive physical activity, but little or nothing in the way of a chemical measure of fatigue has been so far observed as the result of less strenuous work. In particular, it has not proved possible to find a simple indicator of the fatigue resulting from prolonged intellectual effort, though subjectively this appears to be one of the most exhausting of human activities. In fact, measures of heart rate, etc., are really most valuable when we are approaching the limits of performance".

Since it would appear that these experimental measures of fatigue are of little immediate value in the determination of compensating relaxation allowances, work measurement research must be directed to the search for measures which, though probably less accurate, are of more practical value.

industrial fatigue

Definitions of fatigue are many and varied, the devising of tests itself giving rise to explanations of fatigue in terms of test results.

T. A. Ryan [29] defines fatigue as " a general deterioration of the functioning of the individual" and adds that " in the light of present-day information it may be assumed that the principal basis of fatigue is to be found in the brain and nervous system".

J. Goldmark [40] has said: "Fatigue so closes the avenues of approach within, that education does not educate, amusement does not amuse, nor recreation recreate", and is therefore a dangerous condition.

O. G. Edholm and W. F. Floyd [41], on the other hand, reporting on a Symposium on Fatigue (1952) observe: "Perhaps a general mistake is to regard fatigue as an evil. Sherrington said in 1906: 'Therefore . . . fatigue and freshness . . . are physiological factors influencing the result of the interaction of reflex arcs at a common path . . . Fatigue therefore in the long run advantageously redresses the balance of an otherwise unequal conflict. We can recognise in it another agency working toward that plastic alteration of activities which is characteristic of animal life and increases in it with ascent of the animal scale'".

Opening this Symposium, Sir Frederick Bartlett proposed the following definition: "Fatigue is a term used to cover all those determinable changes in the expression of an activity which can be traced to the continuing exercise of that activity under its normal operational condition, and which can be shown to lead, either immediately or after delay, to deterioration in the expression of that activity, or more simply, to results within the activity that are not wanted".

To the fatigue of workers in industry have been attributed reductions in the quantity and quality of work done, and increases in the accident rate, in sickness and absenteeism. Thus, in the Production Handbook [42] industrial fatigue is defined as "that effect of work upon an individual's mind and body which tends to lower his rate or grade of quality of production or both from his optimum performance".

Vernon (1921) [43] points out that "one of the most important objects of fatigue study is to determine whether the fatigue induced by an industrial occupation has an unfavourable influence on the health of the worker. Supposing it be found that health is not adversely affected, then the fatigue incurred, even though it may have been considerable at the time, and have produced severe subjective sensations in the worker, could not be described as abnormal . . . at the same time it must be borne in mind that effects on health do not necessarily show themselves at once".

Writing in 1943, Dr. May Smith [44] says: "When, during the last War, the human problem of industry began to attract attention, it was the subject of fatigue that formed the connecting link between the new application of the science and the older, more theoretical researches, the experimental side of which came from physiological and psychological laboratories. During the past 20 years fatigue in industry has been of relatively little importance, its detrimental effects have been ousted by the increasing number of repetitive jobs, associated with the mental state of boredom. The Industrial Fatigue Research Board became the Industrial Health Research Board in 1926".

Dr. Smith's observations regarding fatigue in industry are confirmed by the findings of Anderson [45] who in his doctorate thesis writes: "Progressive modern manufacturing methods and management are rapidly eliminating real fatigue from industry. At the present time satisfactory outputs at low cost may be had without unduly tiring workers, and in future the fatigue factor in industrial work can be, and probably will be of little importance".

subjective aspects of fatigue

Vernon, in the extract quoted above, speaks of "severe subjective sensations in the worker" produced by fatigue, while Fraser says of "fatigue resulting from prolonged intellectual effort" that "subjectively this appears to be one of the most exhausting or human activities".

Symptoms of fatigue range from muscular stiffness, cramp, pain, eye-strain and headaches to feelings of irritability, lassitude and tiredness. Fraser comments: "Unfortunately, it is possible to get almost any kind of subjective judgment of fatigue going with the same objective performance, so that, while we should never ignore the individual's introspections on this matter, we cannot as yet drive much in the way of useful and consistent information from them".

As early as 1915 Dr. Rivers [46] said: "A distinction must be made between the sense of fatigue — the sensations which supervene during the performance of work — and the lowered capacity for work executed. These conditions, which may be spoken of as subjective and objective fatigue respectively, do not always run parallel courses".

Not all "sensations which supervene during the perfomance of work" are results of fatigue. As Dr. Smith [44] observes, the decline of fatigue in industry has coincided with the greater prevalence of "the mental state of boredom", the external effects of which are hardly distinguishable from those of fatigue.

However, insofar as they result in a diminished capacity for work, the effects of both "true fatigue" and boredom must be catered for by time study in establishing C.R. allowances.

The nature of fatigue is complex and not all of its diverse effects may necessarily require to be provided for in C.R. allowances. On the other hand, it may be necessary to cater for the effects of boredom and other subjective factors which cannot be regarded as emanating from fatigue, although they may interact.

In view of these considerations, it was decided, in this research project, to examine the variations and trends in worker performance as they actually occur in practice.

References will be found on page 206.

Part II will be published in the April issue of the Journal.

REPORT OF THE MEETING OF COUNCIL

Thursday, 30th January, 1958

THE third Council Meeting of the 1957 - 1958 session was held at 10 Chesterfield Street, London, W.1, on Thursday, 30th January, 1958. The meeting, at which the Chairman of Council, Mr. H. G. Gregory, presided, was attended by 33 members. Also present, by invitation of the Council, were Mr. C. L. Clarke, Honorary Secretary, Wales Region; Mr. J. E. Heape, Chairman, Western Graduate Section; and Mr. C. N. T. Manfull, Honorary Secretary, North Midland Region.

Before proceeding with the business of the meeting, the Chairman welcomed Sir Walter Puckey, who had been indisposed. He said Council would also be pleased to hear that Mr. F. T. Nurrish, M.B.E., who had been ill for some time, was now making a steady recovery.

Election of Principal Officers, 1958 - 1959

In accordance with Article 40, the Chairman of Council nominated The Rt. Hon. The Earl of Halsbury as President, and Mr. J. E. Hill and Mr. G. Ronald Pryor as Vice-Presidents, for the year 1958 - 1959.

The election of these officers will take place at the April meeting of Council, when the Chairman and Vice-Chairman of Council will also be elected.

Finance

A report of the Institution's finances, including the Income and Expenditure Account for the period July - December, 1957, was received.

Production Exhibition and Conference, 1958

It was reported by the Secretary that the programme for the Conference was now almost complete, and that a Press Conference would shortly be held to announce the detailed arrangements for both the Conference and the Exhibition. A report was also received from the Exhibition Organisers, Andry Montgomery Ltd.

Institution Awards and Named Paper

The Council unanimously adopted the recommendations of the Finance and General Purposes Committee that the long and distinguished service rendered to the Institution by Mr. E. W. Hancock, M.B.E.; Sir Walter Puckey; and Mr. J. D. Scaife, be recognised by the establishment of the following Named Paper and Annual Awards :-

1. THE E. W. HANCOCK PAPER, to be presented on the subject of " Human Relations in Industry ".
2. THE SIR WALTER PUCKEY PRIZE, to be an annual prize of £50 in cash awarded to a Student showing outstanding performance in the Dip.Tech. or Post Dip.Tech. as applied to production engineering.
3. THE J. D. SCAIFE AWARD, to take the form of a medal awarded for the best Paper published in the Journal each year, with the exception of Named Papers.

National Conferences

The Council adopted the recommendation of the Finance and General Purposes Committee that the Institution should hold national residential conferences only on occasions when a subject of great importance becomes current. The practice of arranging national conferences at fixed intervals of time will be discontinued.

Revised Associate Membership Examination

The Council adopted the recommendation of the Finance and General Purposes Committee that the revised Associate Membership Examination proposals, as submitted to the meeting, should be adopted, and that candidates should be examined under the new syllabus commencing in May, 1960. (Mr. J. France, Chairman of the Education Committee; and Mr. F. W. Cooper, Education Officer, write on pages 199 - 201 of this Journal.)

The Council approved a number of applications for membership and transfer, details of which appear on pages 197 - 198 of this Journal.

The news of the sudden death of Mr. G. A. Firkins, Vice - Chairman of the Membership Committee and Chairman of the Wolverhampton Section, was received with deep regret.

The Journal

It was reported by the Editorial Committee that the full effect of the increased postage rates, which came into force on 1st October last, was now being felt; the possibility of using a lighter weight paper for the advertising section of the Journal, to offset some of the postal increase, was being examined.

There was a good supply of material for the Journal, which enabled the Committee to plan some interesting issues for several months ahead.

The position in regard to advertising was satisfactory, but the Committee reminded Council that the Journal still required the maximum support from Institution members in this respect.

Institution Papers

The Papers Committee were pleased to report the outstanding success of the meeting held at the Royal Institution on 31st October, 1957, when Dr. H. Barrell, of the National Physical Laboratory, presented the 1957 Sir Alfred Herbert Paper. (A report of this meeting appeared in the January, 1958, issue of the Journal.)

Arrangements were complete for the meeting at Bristol University on 6th February, 1958, when Lord Hives would present the 1958 Viscount Nuffield Paper on "Technical Education for Production Engineers".

The 1957 George Bray Memorial Lecture would be presented at the University of Leeds on 24th March next, when Dr. V. E. Yarsley would speak on "The Fabrication of Plastics".

Arrangements for the 1958 series of Named Papers were well advanced.

Research

The following reports were made on behalf of the Research Committee :-

MATERIALS HANDLING GROUP. Three meetings of the Group Committee were held during the quarter. In response to the approach to Regions and Sections, members had been nominated as representatives to the new Group. The inaugural meeting had been held in Leamington Spa in October, 1957, and representatives who had attended were enthusiastic and had promised full support for the future activities of the Group.

The Materials Handling Convention, which was held at Leamington Spa from 28th - 30th October, was attended by some 120 delegates. The method of running the Convention in syndicates proved to be very popular and the gathering, as a whole, was a distinct success. The 1958 Convention would be held at Brighton, in October.

MATERIAL UTILISATION SUB-COMMITTEE. It was hoped that all incoming case studies would be received by the end of January, and that the report of the Sub-Committee would be completed in time for the Production Exhibition in May.

SOURCES OF INFORMATION. The Directory was now in its final stages, and it was anticipated that this also would be available in time for the Production Exhibition.

CONTROL OF QUALITY. The Sub-Committee were now working on the final draft, and it was hoped to achieve publication within the next two or three months.

JOINT RESEARCH COMMITTEE WITH I.C.W.A. There had been no meeting of the Committee during the quarter, but the Sub-Committee were continuing their investigations.

Standardisation

It was reported that the Sub-Committee on International Standards was still in the process of formation, but the Chairman, Mr. T. A. C. Sparling, hoped that it would be complete within the near future.

The British Standards Institution had expressed the opinion, to the Institution representatives on the reconstituted Technical Sub-Committee MEE/6/3—Cutting Tool Nomenclature, that the approach to industry on the points at issue had not been wide enough. The Standards Committee agreed with this view, and had undertaken to furnish the B.S.I. with a list of firms who might additionally be approached in this matter.

Plans had been made by the Joint I.Prod.E./B.S.I. Standing Advisory Committee on the use of standards in industry for the Fourth Conference of Standards Engineers, to be held in London on 21st May, 1958. (Details and application forms appear in the Journal Supplement.) Mr. H. Stafford, Chairman of the Standards Committee, would be Chairman of the Conference.

The Library

The Library Committee were pleased to report a very great increase in the number of enquiries received during the latter half of 1957. In the period September - November, 1957, the Library received more than double the number of enquiries than during the same period in 1956.

Region and Section Reports

The Council received a number of reports from Regions and Sections, extracts from which will be published in the April issue of the Journal.

Sections outside the United Kingdom

The Vice-Chairman of Council (Mr. H. W. Bowen, O.B.E.) said he was pleased to report that Mr. Harold Burke, Past Chairman of Council, would be visiting the Australian Sections next October.

It was agreed that approval be given to the Australian Council for the striking of a special medal to commemorate the James N. Kirby Paper. The Council were much indebted to Mr. G. Ronald

Pryor, Vice-President, who kindly undertook to provide the dies. The question of the exact design of the medal was referred to the Finance and General Purposes Committee for detailed discussion.

Co-operation with the Hungarian Society of Mechanical Engineers

It was reported by the Secretary that an invitation had been received from the above Society, inviting the Institution to co-operate with them in exchanging proceedings, visits and so on.

It was recommended by the Finance and General Purposes Committee, and adopted by Council, that the question of this proposed co-operation should not be pursued at the present time.

National Council for Technological Awards

The Council adopted unanimously the Finance and General Purposes Committee's recommendation that Sir Walter Puckey should be the Institution's nominee as a member of the Board of Studies in Engineering for a further period of three years. beginning in October, 1958.

Honours

The Council warmly congratulated the following members, on whom Her Majesty had conferred awards :-

Companion of Honour

Viscount Nuffield, Hon.M.I.Prod.E.

Knight Bachelor

S. J. Harley.

C.B.E.

W. A. Summers ; C. Metcalfe.

O.B.E.

E. W. Hancock, Hon.M.I.Prod.E.; A. Sykes.

Obituary

The Council recorded with deep regret the deaths of the following members :-

Members

W. C. Gravett; A. McLeod; F. Reaves; S. A. Turner; H. C. Wakley; W. Wilcock; F. G. Woollard, M.B.E.

Associate Members

V. J. Donnelly; B. V. Langhorn; F. Renwick; A. B. Roberts.

Date and Place of Next Meeting

It was agreed that the next meeting of the Council would take place on Thursday, 24th April, 1958, at 10 Chesterfield Street, London, W.1, at 11-a.m.

EXTRAORDINARY GENERAL MEETING

AT an Extraordinary General Meeting of the Institution held at 10 Chesterfield Street, London, W.1, on Thursday, 30th January, 1958, at 2 p.m., a Special Resolution was adopted as follows :-

"That Article of Association 15 be amended * as follows, viz :- In paragraph (c) the word 'may' when it appears for the second time be deleted and the word 'shall" be substituted therefore. This part of the Article to read as follows :

(c) Have passed the Associate Membership Examination prescribed by the Council's examination regulations for the time being, or such other exempting examinations as may from time to time be approved by Council; provided that candidates over the age of 35 who have not passed one of the above-mentioned examinations shall be required to pass only such part or parts of the Associate Membership Examination or to submit such Theses as the Council shall direct."

* The word 'may' in the original Article, was challenged as being ambiguous. The Institution's Council, therefore, felt that this ambiguity should be removed.

REPORT OF THE ANNUAL GENERAL MEETING

Thursday, 30th January, 1958

THE Annual General Meeting of the Institution was held at 10 Chesterfield Street, London, W.1, on Thursday, 30th January, 1958, at 2.05 p.m. Mr. G. R. Pryor, Vice-President, was in the Chair.

Notice convening Meeting

The SECRETARY (Mr. W. F. S. Woodford) read the Notice convening the meeting.

Minutes

The Minutes of the Annual General Meeting held on 31st January, 1957, were taken as read and were confirmed on the motion of Mr. H. STAFFORD, seconded by Mr. F. J. EVEREST, and were signed as correct.

Report on Election of Members to Council

The Report on the Election of Members to Council was received on the motion of Mr. L. SHENTON, seconded by Mr. F. T. DYER.

Annual Report of Council

Mr. H. G. GREGORY (Chairman of Council) referred to the printed version of the Report which was published in full in the January, 1958, Journal. pages 62 - 68. Members would not, he said, expect him to read this report but they might like him to refer to one or two points.

One of the most important decisions in the history of the Institution had been made that day in the Council meeting; namely, the adoption of a completely revised examination structure. Mr. France would talk about this later at a continuation of the Council meeting.

Details of the changes in the examination would be made public in the immediate future, and the new examination would take effect as from the examination to be sat in 1960. The Education Committee had been working on this new structure for four years, and the purpose of revising the examination was to enable the education requirements to be in step with the Institution's policy of broadening the base of membership. Production engineering was slowly emerging as a recognised technology in its own right. The Education Committee had incorporated in the examination provision for the most recent developments in production technology and management, in the hope that it would stimulate universities and technical colleges and other places of learning to offer courses in the most advanced technologies.

Another decision which the Council had taken that day was really relevant to the report to next year's Annual General Meeting. But it was of such importance that he was prompted to mention it: the inauguration of three new awards to commemorate the names of three of the Institution's most distinguished Past Presidents. The Council had decided to establish an E. W. Hancock Paper. Mr. Hancock had given his service to the Institution since its inception, and as long ago as 1931 he served as Chairman of Council. He had always spoken strongly in favour of the development of human relations in industry. It was fitting that the E. W. Hancock Paper should be devoted at each presentation to some aspect of human relations in industry.

The second award was to be known as the Sir Walter Puckey Prize. This would be an annual prize of £50 to be awarded to the Student showing outstanding performance in the Diploma of Technology or in post-Diploma work. This would be an open award. Sir Walter Puckey was Chairman of the Board of Engineering Studies of the National Council for Technological Awards, and the work of the Board under his Chairmanship was having an immense effect on the colleges of advanced technology.

The third award would be known as the J. D. Scaife Award and would be in the form of a medal awarded annually for the best Paper published in the Institution's Journal each year (with the exception of the Named Papers). Mr. Scaife was one of the original founder members of the Institution. He had the unique distinction of having been a member of the Council in one capacity or another ever since the Institution was founded. In the very early days of the Institution Mr. Scaife pressed hard for the Institution to extend its influence over a wide range of industry. In those days his views were considered

too advanced, and it was only in quite recent times that they had come to realise that his vision of the future had been proved to be true.

Mr. Gregory was sure that every member of the Institution would support the Council's action in thus making permanent recognition of the service not only to the Institution, but to the profession of production engineering generally, which these three distinguished Past Presidents had given.

In presenting the report, he did not propose to expand upon the financial position, since this was provided for separately on the Agenda. He would like to say, however, at this point, that the increases in postal and telephone charges as introduced in the current financial year had been a serious blow to the Institution. In asking members to accept a modest increase in the annual subscription last year, the Council hoped that they had made adequate provision for some years to come. The past 12 months had seen the greater part of the increased income taken away by the increase in postal and telephone charges. A large proportion was the cost of sending the Journal to members, a service no one would wish to curtail.

Members could adopt the report knowing that the Council was in full support, and he had the pleasure in moving its adoption.

Mr. E. F. GILBERTHORPE seconded the motion.

There being no questions or comments, the motion for the adoption of the Report was put to the meeting and was *carried* unanimously.

Statement on Income and Expenditure, Balance Sheet and Auditors' Report

Mr. H. G. GREGORY (Chairman of Council). seconded by Mr. C. B. ABBEY, moved the adoption of the accounts.

Mr. R. W. HANCOCK asked whether the item on page 70 — Recovery of Income Tax on Subscriptions — referred to sums it was hoped to recover under covenanting.

Did it mean there had been no effective return from that ?

The SECRETARY replied that for several years just over £2,000 had been recovered; and last year the figure was £2,283. This was not taken into account until the money was actually received. It was not shown as outstanding, because there was always the possibility of an adverse decision in the Courts. They had challenged the Institution this year not because the claim was in doubt. but because another institution of a similar nature had been challenged.

Mr. HANCOCK wondered whether the time might be ripe to press for more members to covenant.

The CHAIRMAN said it might be provident to await the Court's decision. Although it would be a good thing if more members would sign covenants, it must be remembered that where a member's subscription was allowed as an expense, this would not apply.

The motion was put to the meeting and was *carried*.

Election of Auditors, 1957 - 1958

On the motion of Mr. A. BETTS BROWN, seconded by Mr. K. J. HUME, Messrs. Gibson, Appleby & Co., Chartered Accountants, were re-elected Auditors to the Institution for the year 1957 - 1958 and were thanked for their previous services.

Election of Solicitors, 1957 - 1958

On the motion of Mr. J. FRANCE, seconded by Mr. F. G. S. ENGLISH, Messrs. Syrett & Sons were re-elected Solicitors to the Institution for the year 1957 - 1958 and were thanked for their previous services.

Votes of Thanks

The CHAIRMAN said it remained for him to move a vote of thanks, first to Mr. E. W. Hancock, M.B.E., the Immediate Past President. Everyone knew of the wonderful job he had done for the Institution in spite of disability following a serious operation not long before. It was a matter for gratification that for ever more now there was to be a Named Paper for him, in commemoration of his work for the Institution.

Mr. Pryor also moved a vote of thanks to the Chairman of Council, Mr. H. G. Gregory, who had been most assiduous in his duties, and had been a great help to everyone concerned. The Council were very fortunate to have him in the Chair.

Next, he would like to thank Mr. H. W. Bowen, O.B.E., Vice-Chairman of Council, particularly for his difficult work as liaison officer with the overseas Sections.

There was a great deal of talent in the Institution, and its strength was in those people who gave their time and work to it. Members were most grateful to them. He was very conscious that he had not done full justice in moving a vote of thanks to them, but it had been hoped that Lord Halsbury, the President of the Institution, would have taken the Chair. However, he was very happy to move this vote of thanks, in all sincerity.

The vote of thanks was carried by acclamation.

Mr. H. G. GREGORY (Chairman of Council) said he greatly appreciated the Vice-President's remarks and felt sure Mr. Bowen would support him. Anything he had done for the Institution was without any thought of personal gain.

He thanked the Headquarters staff for the help they had given him personally, and particularly Mr. Woodford for the way in which he conducted the affairs of the Institution. The team Mr. Woodford headed was doing a first-class job.

The CHAIRMAN said he would like, from the Chair, to take the opportunity of putting on record that the Institution as a corporate body was most grateful to all who worked voluntarily for it — Region and Section Officers and members of their Committees, and Chairmen and Members of Standing Committees. Their work added up to a

very great amount of effort and was the strength of the Institution.

Mr. R. E. LEAKEY moved a vote of thanks to the Chairman for the way in which he had conducted the meeting and for his indefatigable work for the Institution. This was another example of his help and guidance.

Mr. JACKMAN seconded the motion and thanked the Chairman for his courtesy and efficiency.

The vote of thanks was carried unanimously.

The CHAIRMAN thanked the meeting and declared it closed.

ELECTIONS AND TRANSFERS

30th January, 1958

ADELAIDE SECTION
As Graduates
R. S. Evans; G. B. Wheaton.

BIRMINGHAM SECTION
As Member
A. G. Mosely.
As Associate Member
J. J. F. H. Cross.
As Graduates
K. B. A. Walshe; D. H. D. Southall; K. G. Andrews; N. J. Phillips; R. B. Mills; H. W. Williams; H. J. A. Lester; R. J. Langstone; J. S. Williams.
As Students
B. Fisher; J. T. Stainer; P. Telco.
Transfers
From Associate Member to Member
H. Bennett.
From Graduates to Associate Members
R. D. Homer; J. I. Williams; A. Cooper; R. W. Sandilands.
From Students to Graduates
T. A. A. Burton; R. Harvey; R. O. Parry; L. Tomkinson.

CALCUTTA SECTION
As Associate Member
S. C. Ganguli.

CANADA SECTION
As Student
W. Hornal.

CARDIFF SECTION
As Associate Member
L. Coley.
As Students
D. G. Davies; G. Kinman.
Transfer
From Graduate to Associate Member
A. V. Sullivan.

COVENTRY SECTION
As Member
R. O. G. Booth.
As Associate Members
J. A. Lord; G. C. Shakespeare.
As Graduate
D. A. Armstrong.
As Students
D. Payne; M. W. Hancock; J. C. Jones.
Transfers
From Associate Member to Member
J. L. Adcock.
From Graduates to Associate Members
D. L. Richards; R. R. Lamb; D. N. Everton.
From Students to Graduates
B. E. Morgan; A. Campden.

DERBY SECTION
As Member
J. W. Gardom.
As Graduates
B. R. Garrett; E. Nash.
As Student
K. T. Nelson.
Transfers
From Graduate to Associate Member
D. Lacey.
From Student to Graduate
W. E. Simpson.

DONCASTER SECTION
As Associate Member
J. S. Askwith.

DUNDEE SECTION
As Students
J. W. Anderson; D. M. P. Scott
Transfer
From Student to Graduate
W. A. McLean.

EDINBURGH SECTION
As Graduate
D. Anderson.
Transfer
From Graduate to Associate Member
D. A. Bowman.

GLASGOW SECTION
As Associate Member
J. G. Kerr.
As Graduates
J. Blair; M. M. Sachdev; R. A. Mitchell.
Transfers
From Graduate to Associate Member
H. G. Jones.
From Students to Graduates
D. McWhinnie; J. G. Burrow.

GLOUCESTER SECTION
As Student
V. A. Hyett.
Transfer
From Student to Graduate
D. A. J. Revell.

HALIFAX & HUDDERSFIELD SECTION
As Student
G. R. Blackburn.

IPSWICH & COLCHESTER SECTION
As Graduate
C. Bradley.
Transfer
From Student to Graduate
A. R. Creasey

LEEDS SECTION
As Graduate
B. H. Haigh.
As Student
B. Noble.
Transfer
From Graduate to Associate Member
B. A. Clough.

LEICESTER SECTION
As Associate Member
H. W. Reece.
As Graduates
R. Ramanujan; P. W. Voyle, C. Blockley; C. R. Woskett.
As Students
R. E. Gulliver; E. R. Heggs.
Transfers
From Associate Member to Member
R. Tilsley.
From Graduates to Associate Members
A. F. Todd; J. D. Hopkins.
From Students to Graduates
R. E. H. Bayford; K. B. Chell.

LINCOLN SECTION
As Graduate
R. Thompson.
As Students
P. Whiteoak; J. F. White.
Transfer
From Student to Graduate
R. W. Periam.

LIVERPOOL SECTION
As Graduates
W. Hayes; T. H. McNamee; G. Johnson.
Transfers
From Graduates to Associate Members
D. R. Portman; L. E. Crisp .
From Students to Graduates
J. F. Cliffe; M. Green; J. R. Jones.

LONDON SECTION
As Member
S. R. W. Clarke.
As Associate Members
M. A. Cook; D. J. Connell; P. Harbot; R. J. W. Every; C. N. L. Minister; P. Desmond; G. E. A. Pain; P. J. Egan; B. C. Rhodes.
As Graduates
B. A. Pearson; J. D. Elliott; D. M. Fenton; S. D. Hollander; B. N. Meacham; M. J. Lovell.
As Students
J. M. Berera; B. R. Downer; L. A. Whiting; F. C. W. Maurer; T. A. Hollobone; J. D. Colocott; D. P. Hutchinson; G. W. Berrett; J. Runeckles.
New Affiliated Firm
Production Engineering Ltd.
Transfers
From Associate Members to Members
H. E. Drew; J. R. Moore.
From Graduates to Associate Members
G. V. Harry; C. E. Taylor; E. R. Murray; F. E. Letchford; P. W. Lygo; E. E. Rees; A. B. Merriman; J. M. Ackland; P. Boyd; J. W. Stevens; C. G. Pfaff; C. S. Chanter; H. H. S. Von Der Heyde; R. H. Leaney; P. H. Doncaster; G. R. Willcocks.
From Students to Graduates
J. H. Ede; R. E. Stone; J. D. Webber; J. T. Oliver; J. A. Heaton; J. Tanner; D. W. Minett; J. E. Bridger.

LUTON SECTION
As Member
A. E. Mills.
As Associate Members
A. J. Scarr; T. W. Thorpe.
As Graduates
D. H. Reid; B. P. F. Pemberton; B. E. Holmes.
As Students
P. J. Sear; D. Large; R. G. Joyner.
Transfers
From Associate Members to Members
J. Cherry; C. M. G. Calver.
From Graduate to Associate Member
C. J. Hart
From Students to Graduates
D. A. Slough; C. Halton; H. W. Dilley. G. M. Hayden; E. J. Hunter.

MANCHESTER SECTION

As Associate Member
W. B. Williams.
As Graduate
B. A. Pusey.
As Student
R. H. Thornley.
Transfers
From Graduates to Associate Members
J. Proctor; G. Blemmings.

MELBOURNE SECTION

As Associate Members
P. H. Hall; D. Lazarevic.
New Affiliated Firm
Parish Eng. Co. Pty. Ltd.
Transfers
From Graduates to Associate Members
M. A. Butler; K. W. Hosken.
From Students to Graduates
A. L. Galvin; S. G. Anderson.

NEWCASTLE UPON TYNE SECTION

As Member
J. R. Hendin.
As Associate Member
T. Doyle.
As Graduate
R. Vipond.
Transfer
From Graduate to Associate Member
R. W. Barnes.

NEW ZEALAND SECTION

As Member
J. C. Fantham.

NORTHERN IRELAND SECTION

As Associate Member
W. Luney.

NOTTINGHAM SECTION

As Associate Member
W. L. Hodgkinson.
As Graduate
R. L.Reid.
As Students
W. J. Elder; N. R. Aldred; R. P. Paulson
Transfers
From Associate Member to Member
G. A. Bayley.
From Students to Graduates
K. B. Davis; T. R. J. Reast.

OXFORD SECTION

Transfers
From Graduate to Associate
B. H. Watkins.
From Student to Graduate
H. D. Chapman.

PETERBOROUGH SECTION

As Student
G. D. Nunn
Transfer
From Student to Graduate
I. Wahid.

PRESTON SECTION

As Graduates
A. Gibson; J. T. Lomas; C. R. Southern; T. R. Knowles.

Transfers
From Graduates to Associate Members
H. Fletcher; R. Weir; G. Smith.
From Students to Graduates
G. I. Bishop; J. K. Sagar.

READING SECTION

As Member
H. J. Rowe.
As Associate Member
R. J. Shortley.
As Students
P. H. Reynolds; M. T. Parsons.
Transfer
From Graduate to Associate Member
R. P. Pike.

SHEFFIELD SECTION

As Associate Member
D. E. Rodgers.
Transfers
From Graduates to Associate Members
M. D. Drinkwater; R. Ardron.
From Students to Graduates
R. H. Clark; R. D. Hind.

SOUTH AFRICA SECTION

As Member
H. James.
As Associate Member
G. P. C. Snyman.

SOUTH ESSEX SECTION

As Associate Members
L. Deboo; J. A. Hagley; H. Rogerson; E. V. Williams.
As Graduates
R. J. Rose; D. R. Coburn; D. White.
As Students
J. L. Heath; D. W. Gilson.
Transfers
From Graduates to Associate Members
J. Handley; P. D. Collins; T. C. Carter.
From Students to Graduates
R. R. W. Nichols; J. J. Usher-Smith; H. W. Curtis; M. R. Hulbert.

SHREWSBURY SECTION

Transfer
From Associate Member to Member
G. H. Parlor.

SOUTHAMPTON SECTION

As Graduate
P. J. Orrick.
As Students
D. W. Clinker; R. Gray; E. W. Smith; A. G. Ellis
Transfers
From Associate Members to Members
A. Miskin; S. R. Smith; H. P. Mott.
From Graduate to Associate Member
L. R. Philips.
From Student to Graduate
G. C. Pitt.

STOKE-ON-TRENT SECTION

From Graduates to Associate Members
G. W. Voaden; G. E. Crick.
From Student to Graduate
K. I. Archer.

SWANSEA SECTION

As Member
R. B. Southall.
As Associate Members
A. Slater; D. A. Davies.

SYDNEY SECTION

As Associate Members
C. N. Plummer; G. G. Smith
As Graduate
B. Black.
As Student
W. W. Leal.
New Affiliated Firms
Australian Electrical Industries Pty. Ltd.;
Automatic Totalisators Ltd.;
John Heine & Son Pty. Ltd.;
Electronic Industries Imports Pty. Ltd.;
C. C. Engineering Industries Ltd
Transfer
From Graduate to Associate Member
G. Bennett.

TEES-SIDE SECTION

As Graduate
P. Park.
Transfer
From Graduate to Associate Member
A. W. Lockwell.

WESTERN SECTION

As Associate Member
E. W. Dixon.
As Graduates
P. J Futcher; J. M. Smith.
As Students
J. W. Duggleby; J. M. Rolfe; R. A. Cooper.
Transfers
From Graduates to Associate Members
H. J. Manners; W. J. Sheppard.
From Students to Graduates
G. D. Slegg; R. E. Everhard.

WOLVERHAMPTON SECTION

As Associate Members
Z. H. Formela; W. J. Perks.
As Graduates
G. Akroyd; N. E. Morton; D. E. Bruce; E. G. Holt; F. T. Fox.
As Student
M. A. Winyard.
Transfers
From Graduates to Associate Members
M. Withers; R. F. Brookes; L. D. Done; J. W. Hallam; G. L. Tredwell; P. F. Astbury.

WORCESTER SECTION

As Associate Member
R. D. Turner.
Transfer
From Graduate to Associate Member
K. E. Cole.

NO SECTION

As Associate Members
S. G. Richardson; C. H. Hunt; E. Peel; V. J. Morcombe.
Transfers
From Associate Member to Member
Sze-Yuen Chung .
From Student to Graduate
B. E. Trott.

Because of heavy pressure on space in this issue of the Journal, extracts from the Region and Section Reports presented to the January Council Meeting will appear next month.

THE NEW ASSOCIATE MEMBERSHIP EXAMINATION

An appreciation by the Chairman of the Education Committee,

Mr. JAMES FRANCE, M.I.Mech.E., M.I.Prod.E., M.B.I.M.

ELSEWHERE in this issue of the Journal will be found, within the report of the Council meeting of 30th January last, a resolution approving the proposals of the Institution's Education Committee for revision of the Associate Membership Examination. Included also are particulars of the new examination structure and some notes thereon by the Institution's Education Officer. All those who are interested in production engineering education, however, will probably appreciate some elaboration upon these somewhat austere statements and such is the purpose of this present article.

At the inaugural meeting of The Institution of Production Engineers, on 26th February, 1921, it was laid down that one of the objectives of the new body was " to promote the science of practical production in any branch of industry and to give impulse to methods of production likely to be an asset to members of the Institution and the community ". Any professional institution is essentially an educative body. It is, in the first instance, concerned with providing facilities (usually in the form of lectures, Papers, visits and discussions) for its adult and mature members to continue their never-ending education in the new developments which constantly emerge in their profession. But all this must, if the process is to be truly effective, be built upon an appropriate foundation. Hence the type of early technical education provided for its members is of considerable importance to any Institution. The quality of this foundation determines the ultimate quality of the Institution itself.

An entirely different approach

In those early days, the technical education of engineers was concerned almost purely with problems of design and research. The pioneer members felt, however, that the needs of the manufacturing side of industry necessitated and justified an entirely different approach — one which would embrace the study of production processes, production management and works organisation. A very early report of the Institution's Education Committee pointed out that " the production engineer is essentially a practical economist, a practical organiser and a psychologist ". Although such sentiments are readily accepted today, they were considered very naive when the Institution set up its Education Committee in 1929, charged with the task of propagating them in the technical colleges. Already a few college principals were thinking along the same lines and these joined forces with the Institution in a Joint Examination Board. By 1932, examinations were sufficiently established to justify the compulsory requirement that all junior entrants should have taken the Graduate Examination. Before the end of 1937 the Institution considered that its pioneering work had sufficiently progressed for its then President, Lord Nuffield, and Immediate Past-President, Lord Sempill, to approach the President of the Board of Education requesting the establishment of National Certificates in Production Engineering. This development was even then considered to be quite revolutionary and considerable discussion was necessary before agreement was reached in June, 1939. Actually the commencement of hostilities caused deferment in the introduction of the scheme until 1942.

Introduction of the H.N.C.

The introduction of the Higher National Certificate was of considerable value in lifting the standard of work done in many colleges under the name of production engineering. During and since the last War, the whole country has come to realise the paramount importance of production and the production engineer. As a consequence, and aided by a growing volume of appropriate research, there has been a still further upsurge in quality in the material available for teaching. The universities are taking a growing interest. During 1957 Higher National Diplomas in Production Engineering were established and during this same year college courses in production engineering were recognised for the award of the new Diploma in Technology. Thus, after nearly 30 years of pioneering effort, sustained often in the face of disparagement and ridicule, recognition has been made that production engineering education is a worthy intellectual discipline.

The Institution's own examination was extended in 1951 to embrace the grade of Associate Member, but apart from this had remained unaltered since 1938. Obviously a revision to incorporate post-war technological developments was overdue. But an additional factor had arisen.

The original tenet of the pioneer members laid down in 1921 " to promote the science of practical production in *any* branch of industry ", had, over the years of expansion, become rather dimmed by preoccupation with metal working and the machine tool. During 1946 and 1947 continuous discussions took place at meetings of the Council which culminated in the declared intention to " broaden the

base of membership ". Consequently, when in 1953 Council invited the Education Committee to overhaul the existing examination scheme, it drew attention to the desirability of providing for this statement of fundamental policy.

The task was not an easy one. In considering it, the Education Committee was conscious of two aspects of the problem :-

1. As a first essential, the examination must cater for the whole of the metal working field and not only the finishing end thereof, as it had formerly tended to do.
2. More development work was necessary before the Committee could recommend comparable technological examination standards in the production side of other industries. At the same time the examination structure should be such as to permit this development to emerge.

Accordingly an examination structure has been devised which it is hoped will prove in practice to meet these requirements. An explanation of this will perhaps be appropriate here.

In order to meet the condition of catering for the whole of the metal working field, it is essential that the approach be via fundamental principles. Thus, for example, in the subject of "Production Metallurgy — Forming and Joining" the syllabus is first concerned with the basic property of plasticity and then proceeds to show how this property is exploited in widely differing production processes. Similar treatment is given to other technological subjects in Group B of Part II.

This fundamental approach must of necessity be erected upon a foundation of basic science. Part I has always been concerned with such but has now been considerably strengthened. It was felt that Physics must be added but for the sake of standardisation, which will no doubt be appreciated by educational authorities, it was decided to follow the pattern set by the Engineering Institutions Part I Committee. This, of course, divides Physics into two constituent papers — Heat, Light and Sound, and Principles of Electricity. Production Processes is the new name for an improved version of Workshop Technology — a subject considered essential for the metal working production engineer. For production engineers in other industries this may not be true, hence they may offer Chemistry as an alternative.

Group A of Part II gathers together subjects of a basic nature. Although six of these are listed it should be borne in mind that the selection of one only is insisted upon — although a second may be added at the candidate's choice. It is desirable that the subject chosen from this group be directly related to those selected in Group B but the Education Committee lay down no hard and fast rule in this. Generally speaking, the study of subjects in Group B will demand a prior knowledge of a certain subject or subjects in Group A, and it is felt that this fact alone will take care of the combinations offered by candidates.

Group B comprises the specialised technological subjects of production engineering. Predominantly these are concerned with the metal working industries, the exception being Non-Metallic Materials. From time to time it is hoped to add to this section further subjects relating to industrial activities other than metal working. Part I and Part II, Group A, contain the basic science necessary to support such subjects.

In Group C are those subjects of fairly recent development which some think of as related more to managerial topics than to those of technology. It is felt that as time passes they will come more and more to be recognised as technological in character and hence rightly included in Part II. All these subjects are applicable to any type of industry.

Some critics might deplore the inclusion in Group A of such subjects as Advanced Mathematics. Should, however, a candidate be making a specialised study of, say, Applied Statistics and Operational Research for Group C, it is surely appropriate to allow him to offer Advanced Mathematics in Group A if he wishes to do so.

Great care has been taken in the groupings of Part II to prevent candidates avoiding the study of subjects which are essentially of a production character.

The Education Committee feel that no one with the education of production engineers at heart will quarrel with the inclusion of the three subjects now listed in Part III ; nor with the decision that the study of these be compulsory for those desiring Associate Membership of the Institution.

No drastic changes

In practice, many colleges now offering production engineering courses will not find it necessary to make drastic changes in their structure of courses to meet the Institution's new requirements. Those including, for example, Materials and Machines; Jig and Tool Design; Machine Tools and Metrology under the old scheme will find these same subjects, albeit under somewhat different titles, still appearing in and completely satisfying the requirements of the new Part II, The fact that the Institution's new syllabuses are of considerably higher standard than the old will also not be any embarrassment to those colleges who have consistently kept their teaching in line with modern developments. Where colleges have not done so, then considerable change might well be needed — indeed to encourage this is one of the primary aims of the Institution. Colleges specialising on the metal forming group of subjects may need to make somewhat wider changes in their course structures, although these will probably not be great.

It is hoped that the declared intention of the Institution to be bold in its readiness to add to Group B of Part II new subjects in wider fields of industrial production activity will stimulate colleges to develop such subjects, secure in the knowledge that, provided their academic standard is adequate, they will be welcomed by the Institution.

The standard of technical education now demanded by the Institution of its prospective members is far and away higher than when first it imposed examination conditions. But the standard of performance of production engineers demanded by industry today is also increased in like measure, and who can tell what will be the demands upon them during the next 25 years ? This is the justification for the new examination scheme. Capable young men, adventurous and confident, do not, when choosing their future careers, look for the soft options but declare unhesitatingly for the worthwhile and the difficult. These are the young men that the profession of production engineering needs and for whom there are good prizes in productive industry. The new examination requirements are offered as a challenge and an opportunity to them.

THE STRUCTURE OF THE NEW EXAMINATION

The Examination remains in three parts, I, II and III.

PART I has been extended from five to seven papers, the subjects of Heat, Light and Sound and Principles of Electricity having been added as essential basic science subjects. Chemistry is allowed as an alternative to Production Processes for students engaged in appropriate fields.

PART II is in three Groups, A, B and C, the total of four papers remaining unaltered.

Group A continues at a more advanced level the basic science subjects and the addition of Advanced Mathematics, Applied Physics, and Applied Chemistry will be noted.

Group B comprises the specialised technologies, the metal-forming group being replaced by two papers in Production Metallurgy, namely, Melting and Casting, and Forming and Joining. Plastics Technology is superseded by Non-Metallic Materials.

Group C comprises three new subjects together with Process Study and Work Study. The subjects are Control Engineering, Factory Layout and Materials Handling, Applied Statistics and Operational Research.

PART III comprises three management papers all of which must be taken. This Part has been substantially re-shaped and strengthened with the addition of only one hour examination time. Industrial Management forms the basic subject, the two remaining papers being Management of Production and Management of Men.

The new structure

The structure of the Institution's Examination as applicable in and after 1960 is :

PART I (seven three-hour papers)

English ;
Mathematics ;
Applied Mechanics ;
Engineering Drawing ;
Heat, Light and Sound ;
Principles of Electricity.

In addition to these six papers, there must be taken either :

Production Processes ; *or*
Chemistry.

PART II (four three-hour papers)

Group A (at least one paper to be taken)

Advanced Mathematics ;
Advanced Applied Mechanics ;
Metallurgy ;
Electrical Technology ;
Applied Physics ;
Applied Chemistry.

Group B (at least two papers to be taken)

Theory of Machine Tools ;
Tool Design ;
Metrology ;
Production Metallurgy — Melting and Casting ;
Production Metallurgy — Forming and Joining ;
Non-Metallic Materials.

Group C

Control Engineering ;
Process Study and Work Study ;
Factory Layout and Materials Handling ;
Applied Statistics and Operational Research.

PART III (three papers : for Industrial Management three hours is allowed; for the others two hours)

Industrial Management ;
Management of Production ;
Management of Men.

Syllabuses and specimen examination papers are now available and may be obtained on application to the Publications Department of the Institution. The booklet "Subjects and Syllabuses for the Associate Membership Examination" is issued free. The charge for specimen papers is now 1/- per subject, and 3/6 per set.

"Notes for Guidance" (available only on application from establishments of further education) ; "Exempting Qualifications from the Institution's Examinations" ; and a revised "List of Text Books on Production Engineering" are in course of preparation and will be available shortly.

F.W.C.

news of members

Mr. David H. Bramley, Member, has joined the board of Geo. Salter & Co. Ltd., West Bromwich. This appointment is in addition to Mr. Bramley's responsibilities as Head of the Department of Industrial Administration at the College of Technology, Birmingham, a position he has held since 1947.

Mr. F. W. Daniels, Member, has been appointed Chairman of T. H. & J. Daniels Ltd., Stroud, Gloucestershire. He is also Chairman of Daniels (Cam) Ltd.

Mr. A. O. R. Johnson, Member, has been appointed Managing Director of T. H. & J. Daniels Ltd., Stroud, Gloucestershire.

Mr. J. Loxham, Member, has been appointed Professor and Head of the Department of Aircraft Economics and Production at The College of Aeronautics, Cranfield, and will take up his duties on 1st April, 1958. Mr. Loxham has been Managing Director of The Sigma Instrument Co. Ltd. since 1939.

Mr. M. C. Timbury, Member, has been appointed a Director of Barr & Stroud Ltd., Glasgow. Mr. Timbury is a member of the Glasgow Section Committee.

Mr. A. J. Beanland, Associate Member, has been appointed Group Sales Director of The Lancashire Dynamo Group. Mr. Beanland, who will be a Director of Lancashire Dynamo Group Sales Ltd., will be in charge of the L. D. Group Sales Organisation at home and overseas.

Mr. C. A. I. Blackwell, Associate Member, has recently been promoted to the position of Works Engineer with Rhodesian Alloys (Pvt.) Ltd., of Gwelo, Southern Rhodesia.

Mr. P. A. Broadbent, Associate Member, has relinquished his appointment as Technical Assistant to the Works Director (Light Alloy Foundries) of Sterling Metals Ltd., Coventry, and is now Technical Representative with the Birfield Group, London.

Mr. P. H. Bhanot, Associate Member, has been posted to the Central Examination Organisation, Civil Aviation Department, Bamrauli, Allahabad (India). Mr. Bhanot hopes soon to visit the United Kingdom for a Familiarisation Course of training to cover new aircraft and to visit some new aircraft engine factories. The course of training would be arranged by the British Council under the Colombo Plan, for a period of 6 - 7 months.

Mr. A. G. Coltman, Associate Member, has relinquished his position as Engineer with Smith's Aircraft Instruments Ltd., Cheltenham, and has now taken up an appointment as Production Engineer with the Automobile Products Division of Smith's Motor Accessories Ltd., Witney.

Mr. H. Dyson, Associate Member, has been appointed Technical Superintendent of the Tool Division of David Brown Industries Ltd., Huddersfield.

Mr. W. J. Edmonds, Associate Member, has recently relinquished his position as Staff Engineer in charge of Car Transmissions and Rear Axles with the Ford Motor Co. Ltd., and has taken up an appointment as a Lecturer in the Engineering Department of the South East Essex Technical College.

Mr. A. Eilmore, Associate Member, is now Works Manager of British Ropes Ltd., Gateshead.

Mr. J. A. Freel, Associate Member, is Senior Electronics Estimator with The English Electric Co. Stevenage, Hertfordshire.

Mr. C. D. Macmillan, Associate Member, who was Head of Department of Mechanical Engineering at the College of Technology, Rotherham, has now taken up an appointment as Principal of the Technical College and School of Art, Keighley.

Mr. R. W. Marks, Associate Member, General Manager of Manwood, Miller & Co. Ltd., Stalybridge, has in addition to his existing responsibilities been appointed a Director and General Manager of the recently created Company, M. M. Plastics Ltd

Mr. J. M. Rattray, Associate Member, has recently been appointed Works Manager of Haywards Ltd., at Enfield, Middlesex.

Mr. C. F. Brigginshaw, Graduate, has been appointed General Works Manager of Byron Business Machines, Nottingham.

Mr. A. C. S. Ensell, Graduate, is now a Manufacturing Engineer with the Industrial Gas Turbine Division of the Westinghouse Corporation. Philadelphia, U.S.A.

Mr. W. G. Hearle, Graduate, has taken up a new appointment as Chief Estimator at the Chester branch of the De Havilland Aircraft Co. Ltd.

Mr. L. Rodwell, Graduate, has relinquished his position of Grade 'B' Assistant at the South East Essex Technical College, and has taken up an appointment as Lecturer in Production Engineering in the Industrial Engineering Department at Loughborough College of Technology.

Mr. T. K. Tapp, Graduate, has recently left the U.K. to take up a production engineering appointment with The Russell Manufacturing Co. Pty. Ltd., Melbourne, Australia.

DIARY FOR 1958

24th March	**The 1957 George Bray Memorial Lecture,** to be presented at the University of Leeds. Speaker: **Dr. V. E. Yarsley.** Subject: **"The Fabrication of Plastics".**
9th and 10th April ...	Conference on **"Compressed Air in Industry"**, Camborne, Cornwall.
12th - 21st May ...	**Production Conference and Exhibition,** Olympia — **"Production Fights Inflation".**
21st May	**Fourth Conference of Engineers** and those responsible for Standards matters in Industry, London.
27th - 31st August ...	**Annual Summer School,** Ashorne Hill, Warwickshire.
13th, 14th, 15th October	**Materials Handling Convention,** Brighton.
29th October	**Annual Dinner of the Institution,** Dorchester Hotel, London.

GROUP PROVIDENT SCHEME

THE Institution has a Provident Scheme for its members. The object is to safeguard members against the expense of private treatment for major illnesses, including surgical operations. Private treatment in nursing homes, hospital pay-beds and private specialists' consulting fees, do not come under the National Health Service, and the patient has to pay the full cost. The Provident Scheme is designed to enable members of the Institution, and their dependents, to make the best and speediest arrangements without having to worry about the cost, and to provide a measure of privacy during treatment which is not possible under the National Health Service. Thus the Scheme is not intended to displace the National Health Service, but to provide supplementary benefits.

Under the Institution's Group Provident Scheme, the British United Provident Association's standard rates of subscriptions are reduced by 20% and arrangements are made for the collection of subscriptions annually by Banker's Order made payable to the Institution. Members are entitled to benefit immediately on acceptance and are not subject to the usual three months waiting period.

If you are already a private member of the B.U.P.A. and under 65 years of age, you can apply to transfer to the Institution's Group Scheme and get the benefit of 20% reduction in fees. A refund of any balance of your current individual subscription which may be outstanding, would be made.

Members interested in joining this Group Scheme are asked to write to the Secretary of the Institution, asking for full details and an application form.

Obituaries

Mr. FRANK WOOLLARD, M.B.E.

Past President, Institution of Automobile Engineers.
Member, Institution of Mechanical Engineers.
Member, Institution of Production Engineers.
Member, Society of Automotive Engineers, U.S.A.
Founder Member, British Institute of Management.
Hon. Member, Motor Industry Research Association.
Hon. Associate, College of Technology, Birmingham.

ON 22nd December, 1957, Frank Woollard died at the age of 74, and The Institution of Production Engineers, in common with many other professional engineering and management circles of which he was a distinguished member, suffered the loss of one of its most active thinkers and pioneers.

Recognised internationally in his later years as one of the fathers of the British motor industry, Frank Woollard was throughout his life an active champion of automatic mass production techniques, and of modern management methods. Many of the principles which he pioneered in the automobile industry, from the time of his association with Lord Nuffield in the early 1920's in Coventry, have now become established widely as the basis for modern transfer machine design and operation throughout the world.

Starting as an engineering apprentice in the railway workshops at Eastleigh, at the turn of the century, he entered upon his long career in the automobile industry, first as a designer and successively as production engineer and works manager and director. In 1932 he was appointed managing director of Rudge Whitworth Ltd., and from 1936 until his retirement a few years ago he was a director of The Birmingham Aluminium Casting Co. Ltd., and of the Midland Motor Cylinder Co. Ltd.

Frank Woollard had an outstanding flair for smoothing out complex situations and for engineering the right kind of atmosphere where personal animosity had no place and fruitful thought and joint effort for a lasting solution quickly took predominance. He was thus outstandingly successful as chairman of an executive committee.

This flair was used to good effect when he took a leading part in the discussions and negotiations which led to the successful merger between the Institution of Automobile Engineers and the Institution of Mechanical Engineers in 1947. He was at that time President of the Institution of Automobile Engineers and after the amalgamation became the first chairman of the new Automobile Division of the Institution of Mechanical Engineers.

He took a great interest in fostering technical developments during and after the War years and took a leading part in the Councils of The Aluminium Development Association, The Zinc Die Casting Association and The British Cast Iron Research Association. Similarly, he gave much time and effort to committee work in professional engineering and management institutions, and to the preparation and presentation of lectures. These were always prepared with meticulous care and attention to detail and illustrations, and he invariably attracted and held the interest of his audience.

Retirement after such an active industrial and professional engineering career was impossible for Frank Woollard. Characteristically he sought and found an ideal solution which enabled him to promote, in the most effective possible way, those principles and ideals in flow production methods, industrial organisation and human relations, which he had employed so successfully in his own career.

His particular solution might not have suited anyone less dedicated to the service of others, or less optimistic about the industrial future! It was to engage upon an extensive programme of lectures, in authorship and in post-graduate level discussion and teaching in production engineering and management subjects at the University and College of Technology in Birmingham. In all these his personal experience of the impact of technical advance on management and men gave his books and teaching a unique authority.

Many will remember the inspiring and thoughtful Paper which he presented at the 1955 Margate Conference of the Institution, on the benefits and effects of automation. This Paper was much reprinted and widely circulated, as it served to dispel many of the then current misconceptions regarding the nature and possible

social effects of automation. His most important book, "The Principles of Mass and Flow Production", was published in 1954, and summed up a lifetime of knowledge and experience in production engineering and management. Part of his own philosophy is expressed in his dedication of this book "to all those who seek to lift the curse of Adam from the shoulders of mankind".

All his life, Frank Woollard never spared himself when he could serve others and during the last few years, although often in considerable pain and discomfort, he continued faithfully to keep his many lecture appointments on important professional platforms in all parts of the country, and to meet his group of post-graduate students, until a few weeks before his death.

All those who knew Frank Woollard personally and many who heard him speak will remember him as a kindly personality, gifted and philosophical, to whom one could turn for advice and help. They will remember his humour, the apt turn of phrase, his twinkling eyes, the direct look and the sincere interest which he always showed for the welfare of his colleagues and of his students. The knowledge and ideas which he gathered in his books and lectures, together with the great machines and industrial organisations which he pioneered and helped to build up, will long remain as a memorial to him. T.U.M.

Mr. ALASTAIR McLEOD, M.I.Prod.E.

IT was with great regret that his many friends learned of the death, on 3rd January last, of Mr. Alastair McLeod. He will long be remembered for his charming personality and unfailing wit and good humour. To spend a few hours in his company, whether on business or pleasure, was indeed a tonic.

Coming to London in 1937 from Edinburgh, where he was born and received his metallurgical training, he took up journalism, joining the staff of Industrial Newspapers Ltd., and at the time of his death he was Managing Editor of "Sheet Metal Industries", "Metal Treatment and Drop Forging" and various other journals.

During his 21 years as an editor he travelled extensively on the Continent and there was rarely a metallurgical conference held which he did not attend and report on for the benefit of his readers ; in so doing he acquired an international circle of friends and a reputation of being one of the leading authorities on rolling mill practice.

He devoted considerable time to the work of the Institution, serving on the London Section Committee, the Technical and Publications Committee of which he was for a period Chairman, and eventually as a Member of Council ; also, through his numerous contacts, he was able to arrange many interesting lecture programmes. He also represented the Institution on a number of B.S.I. Technical Committees.

In spite of his many professional activities he found time to devote to youth organisations and was also a keen competition motorist.

In later years he suffered severely with rheumatism, and those of his friends who were close to him were constantly amazed at the cheerful manner in which he surmounted the handicaps of this painful affliction and carried on "as before".

It was indeed a fitting tribute to "Mac's" memory that the cremation service was attended by so many of his friends, a large number of whom had travelled considerable distances to be present. R.K.

Mr. G. A. FIRKINS, M.I.Prod.E.

THE sudden death in January last of Mr. George Arthur Firkins, Chairman of the Wolverhampton Section, came as a shock to his many friends and colleagues in the Institution.

Mr. Firkins, who was a Consulting Engineer, was a native of Malvern and was educated at Glasgow Technical College. He played a very active part in the aircraft industry during the War, and subsequently became Manager of the Red Wing Aircraft Company, Wolverhampton. He later founded the firm of G. & A. Firkins, engineers, in Wolverhampton.

Mr. Firkins was a prominent figure in Institution activities; in addition to his Chairmanship of the Wolverhampton Section, he was Vice-Chairman of the Membership Committee, and also served on the Midlands Region Committee.

OUTPUT PATTERN IN REPETITIVE TASKS

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1957/58

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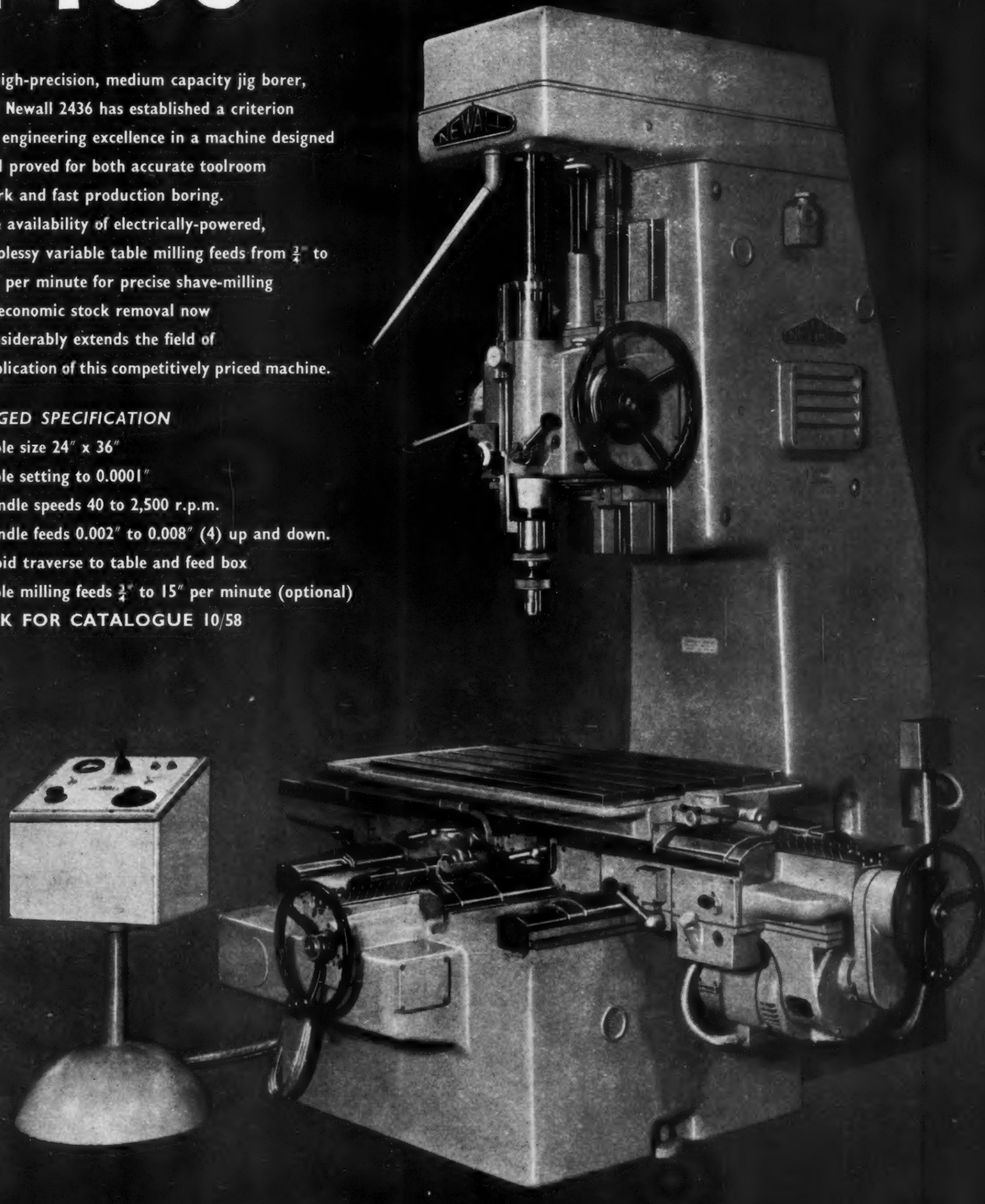

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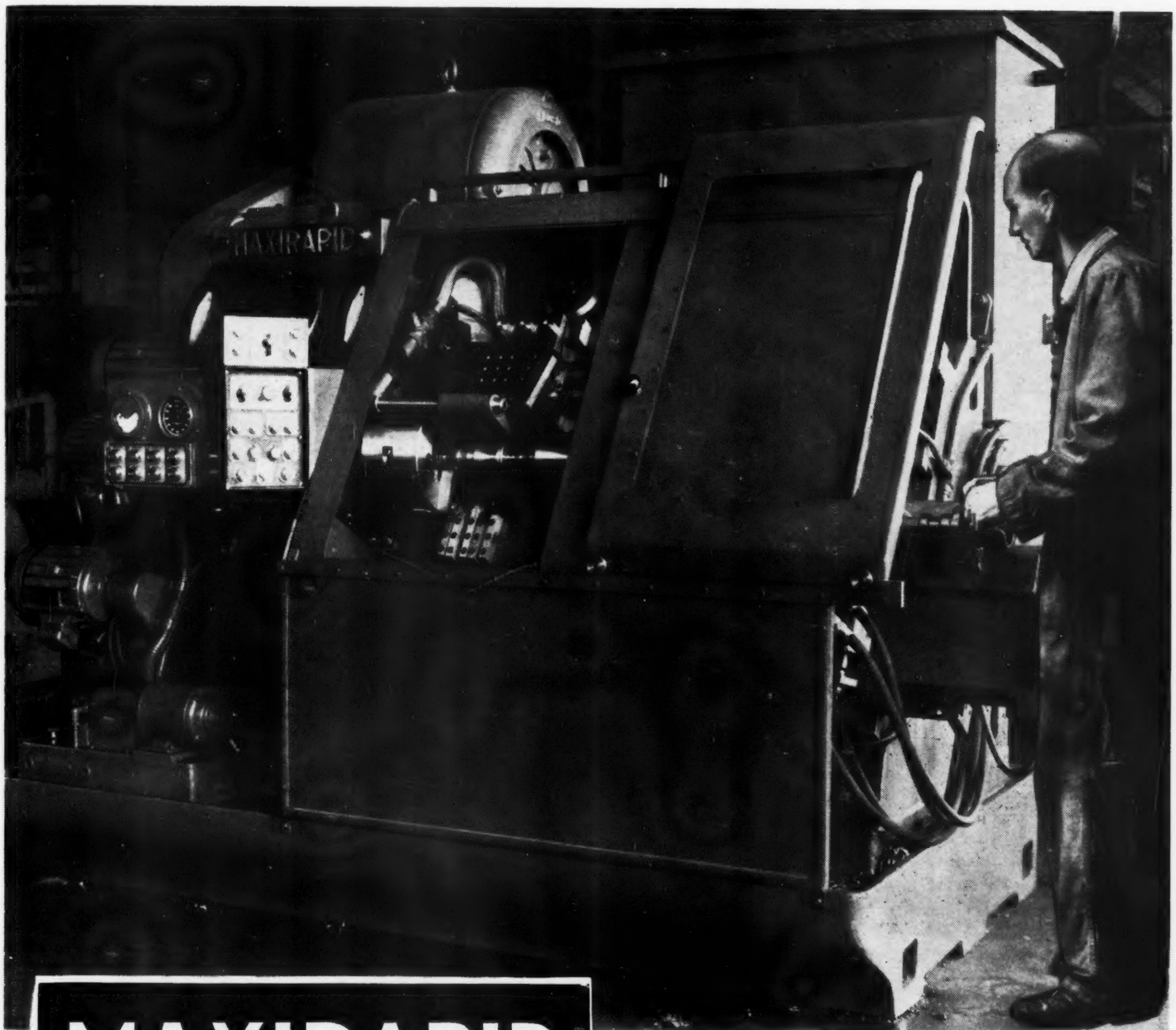

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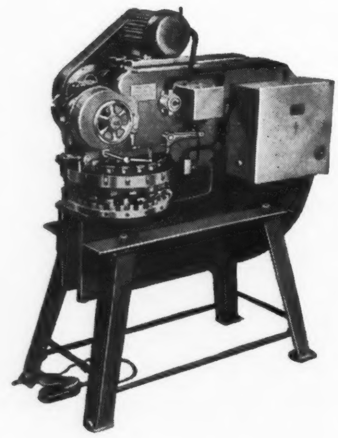

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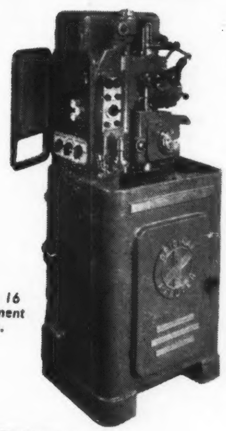

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P 250	10	6½	7
DRA DUPLEX	10	10	3
P 400	15¾	11¾	4¼
P 500	20	14	3
RS 1V	29½	12½	3
P 900	35½	15	3.2
RS 2V	39½	14½	2½
P 1250	49½	19¾	2.1
RS 3V	71	21	2½
P 1800	71	24¾	1⅜
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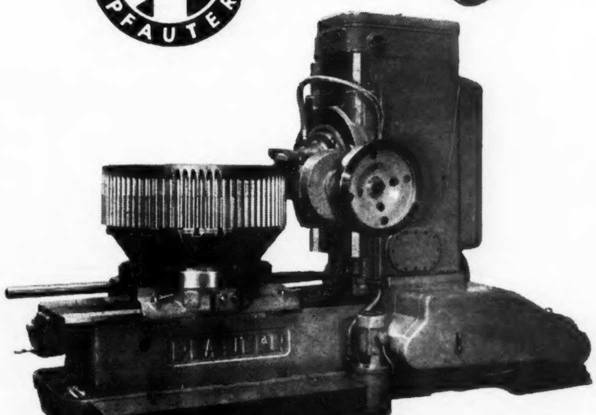

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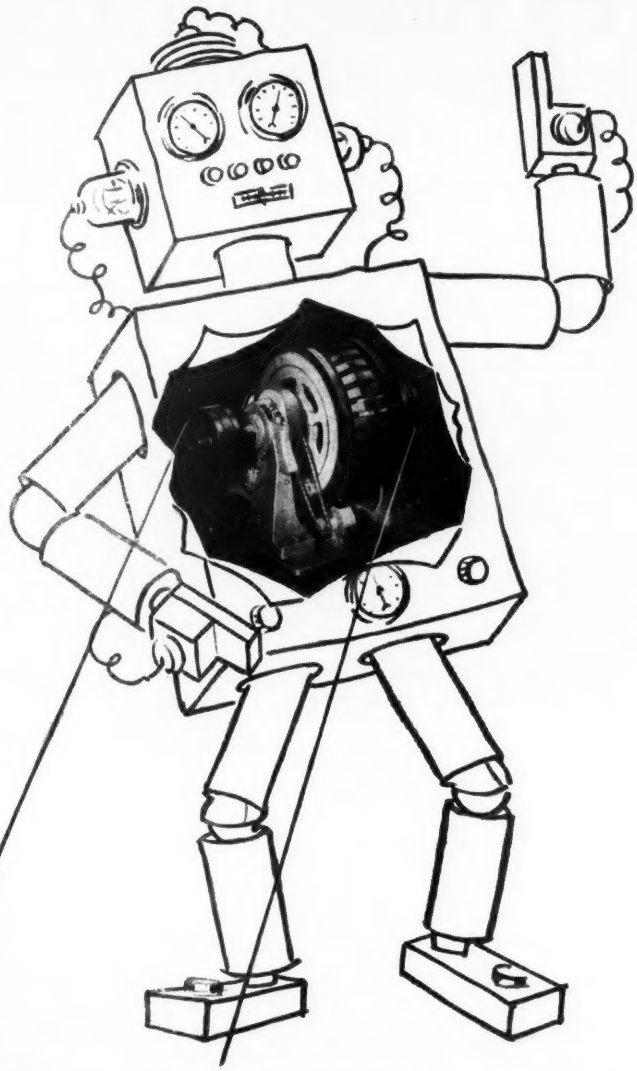

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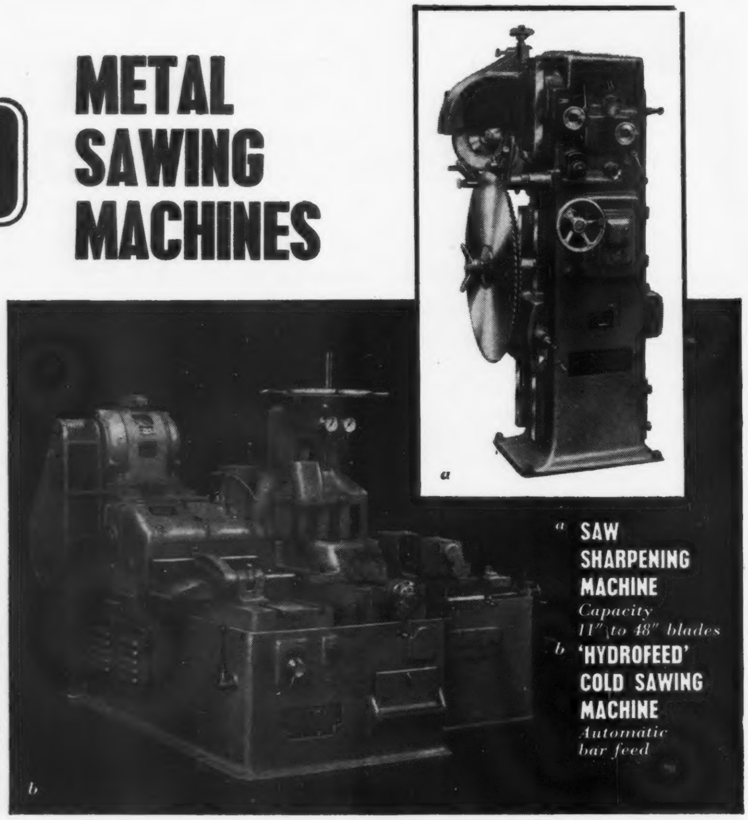

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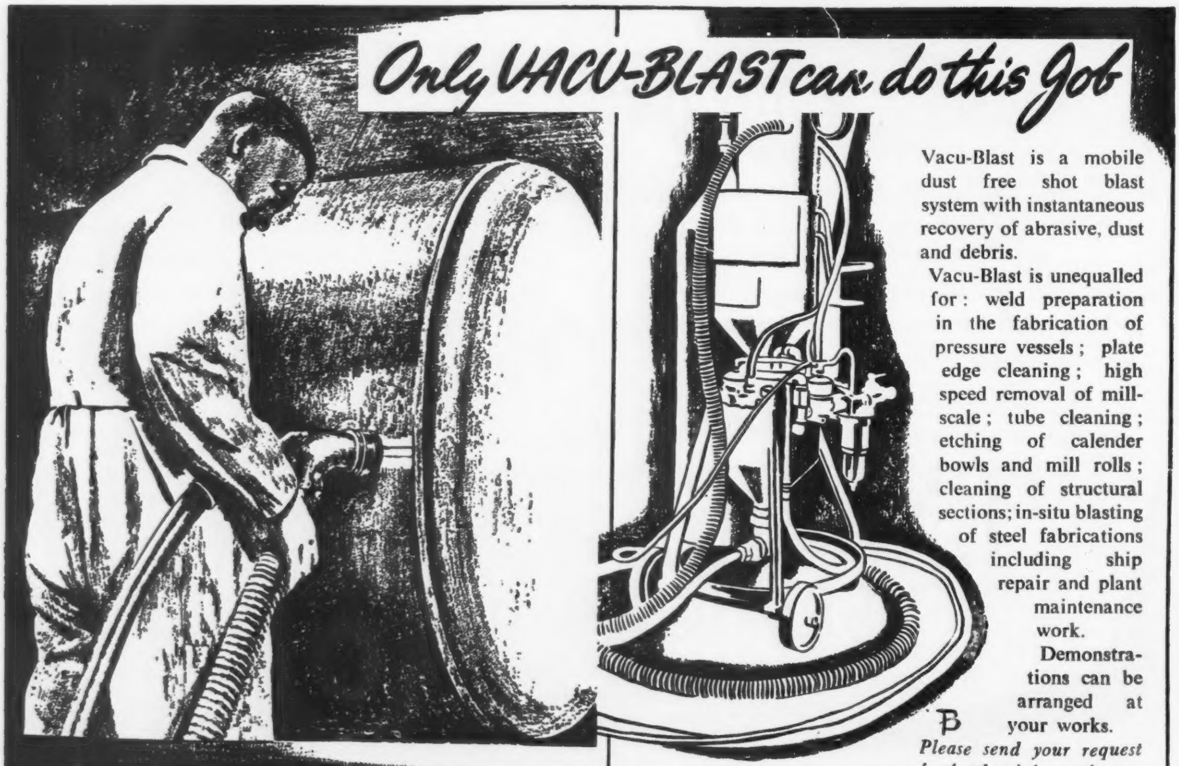

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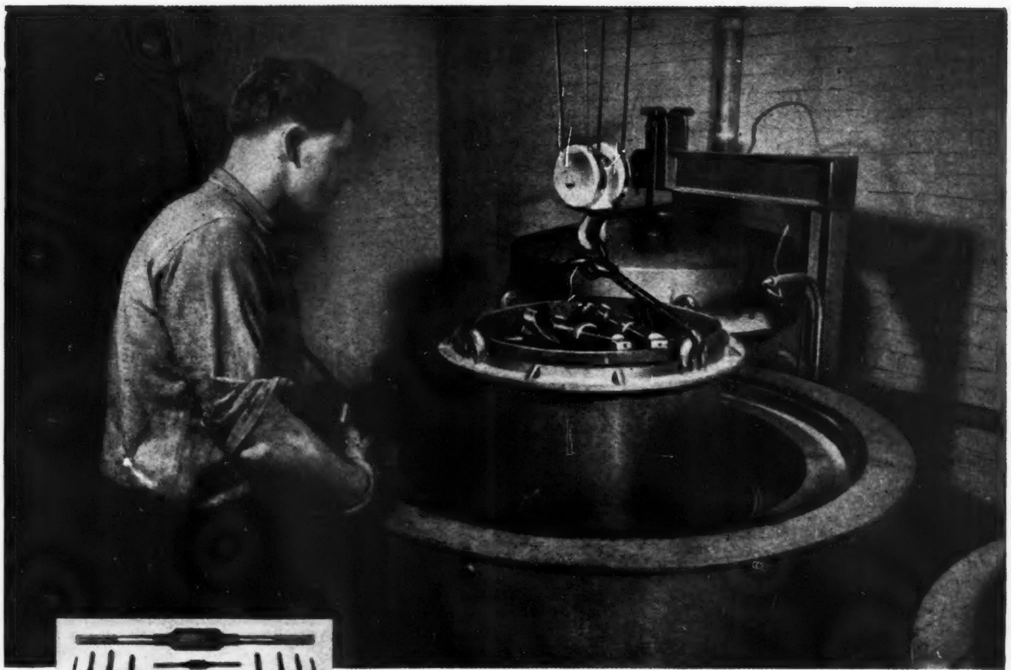

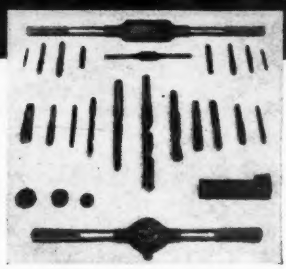

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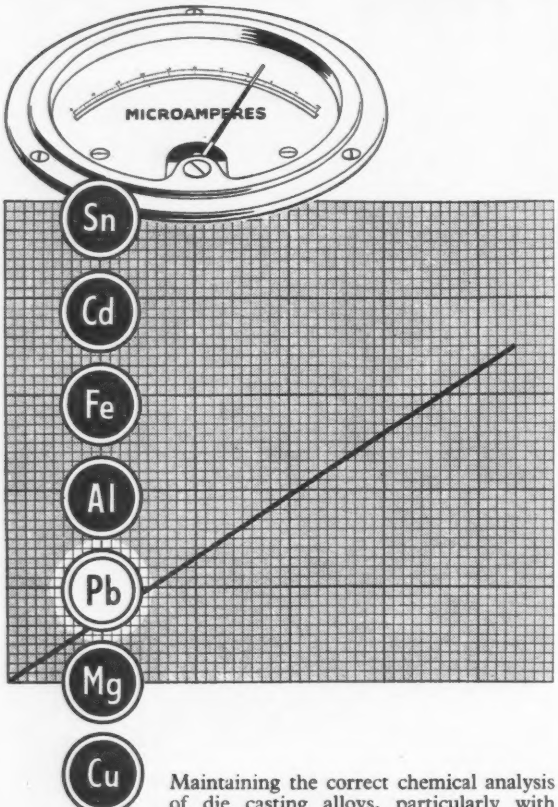

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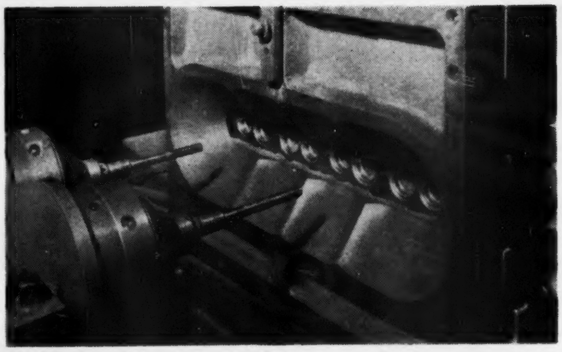

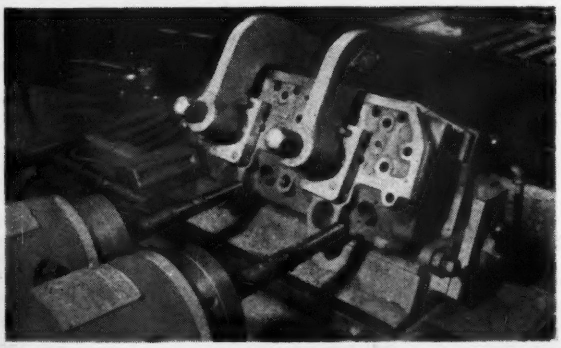

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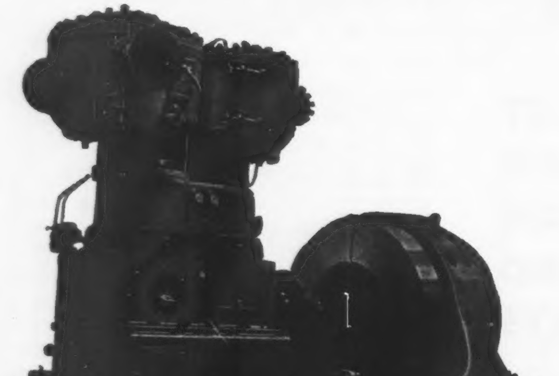

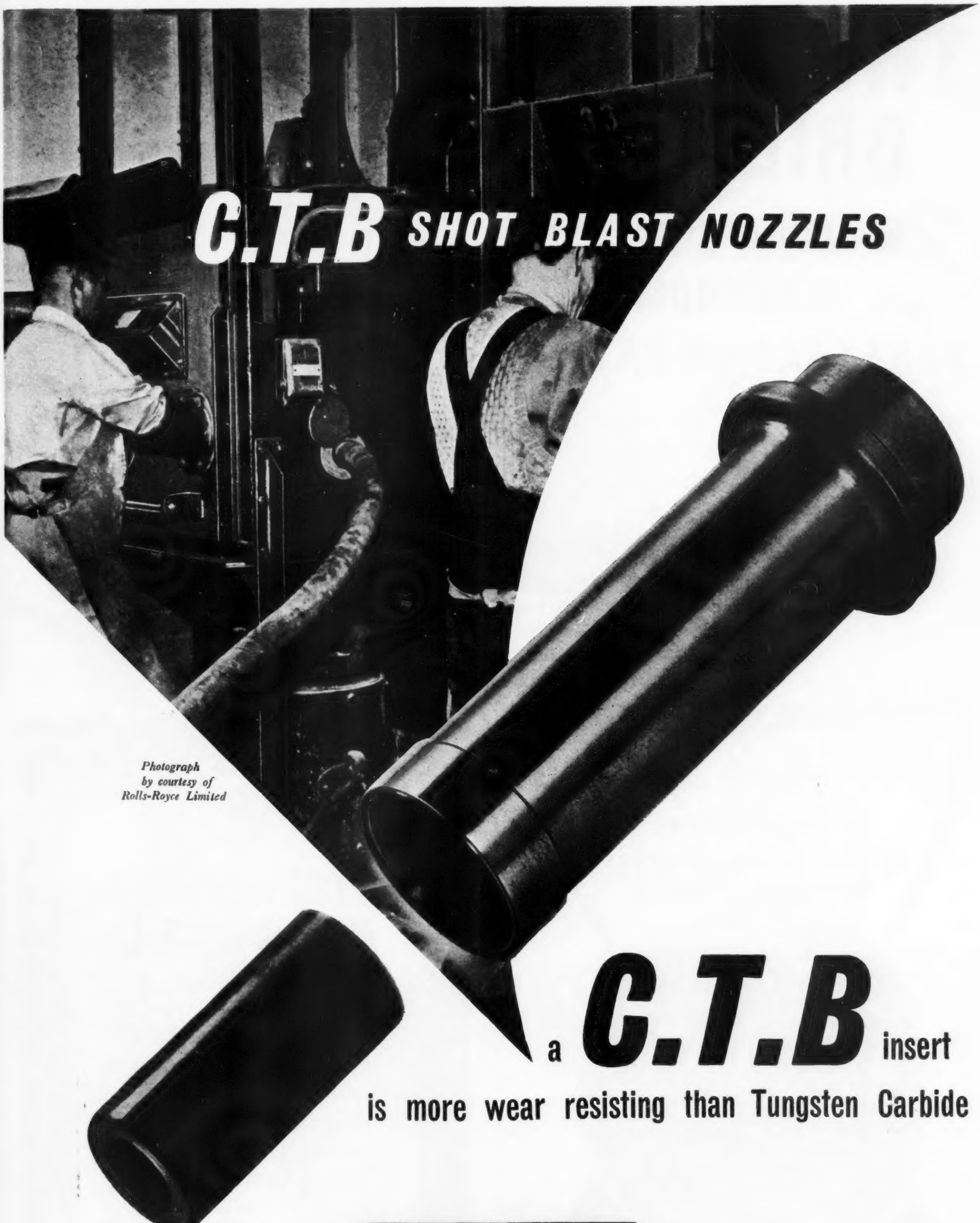

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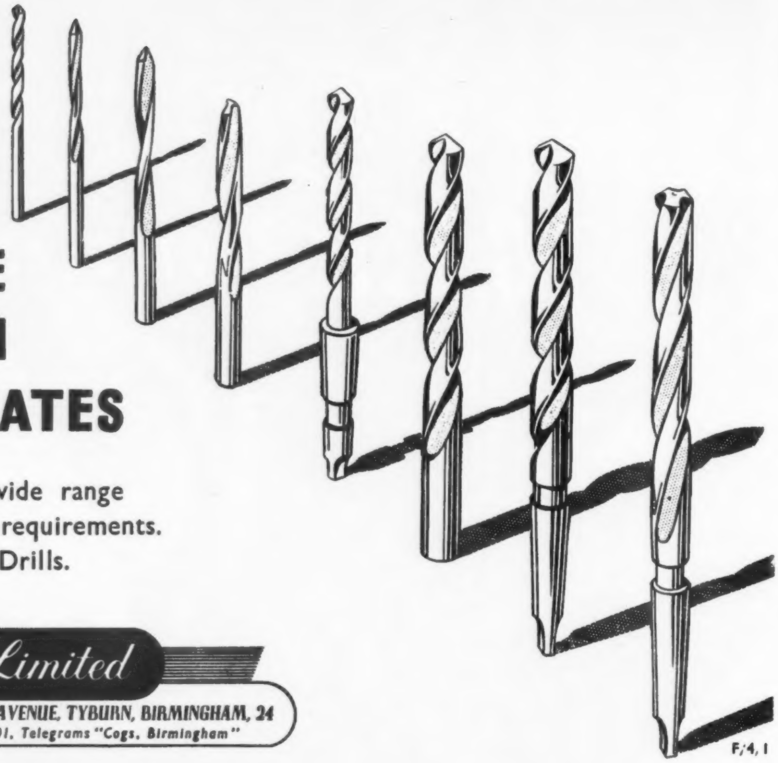

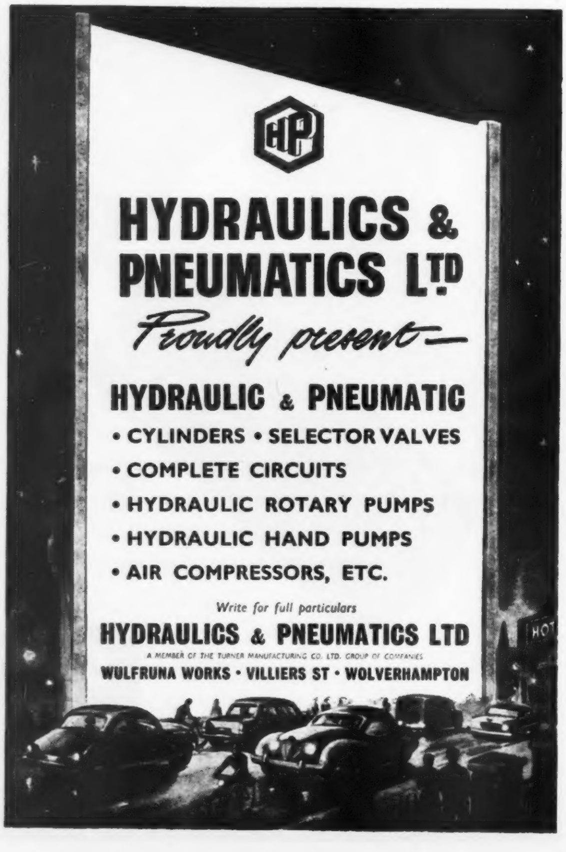
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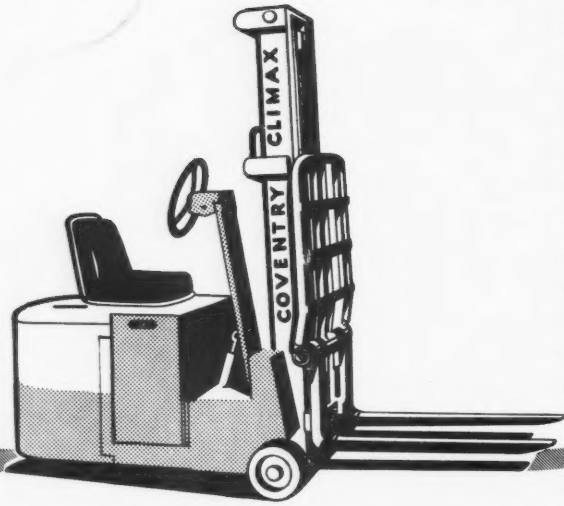

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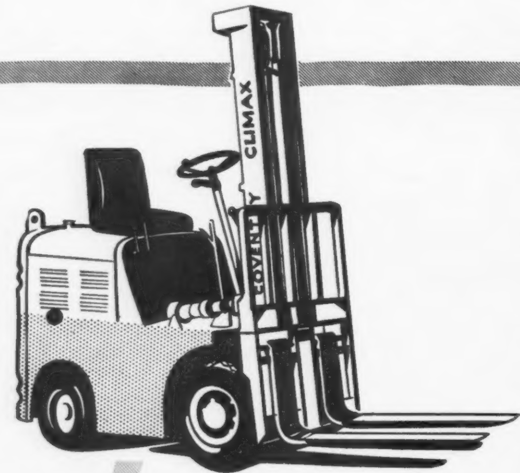

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